DOCTOR OF PHILOSOPHY

An Environmental Health Information System Model for the Spatiotemporal Analysis of the Effects of Air Pollution on Cardiovascular Diseases in Bangalore, India

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An Environmental Health Information System Model for the Spatiotemporal Analysis of the Effects of Air Pollution on Cardiovascular Diseases in Bangalore, India

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Abstract

This study attempts to answer the research question 'Can a novel model of health information system strengthen process for conducting research to understand the effects of air pollution on CVD in developing countries?'

There is limited research output from Asia and in particular, from India on studies of the deleterious effects of air pollution on CVD. This research aimed to investigate the barriers in developing countries and proposed the use of a spatiotemporal methodology to assess the effects of air pollution on CVD by developing an application based on a GIS platform. Choosing Bangalore as a case study area, secondary data from various governmental departments that included demographic data, air pollution data and mortality data were obtained.

An Environmental Health Information system application based on GIS platform was developed specifically for Bangalore and with the characteristics of the datasets available. Data quality assessment was carried out on these datasets that resulted in the recommendation of a generalisable data quality framework to enable better data collection that will aid in strengthening health development policies. The data was analysed using spatial and non-spatial techniques. Results showed that levels of PM10 were of concern to the city with all areas having either high or critical levels of pollution. CVD deaths also were of concern contributing to almost 40% of total mortality. The potential years of life lost (PYLL), which is an estimate of the average years a person would have lived if he or she had not died prematurely was calculated for the years from 2010 to 2013; this revealed that 2.1 million person years were lost in Bangalore due to CVD alone. These potential years lost is an important factor to consider, as preventive measures taken by the Government will result in a significant economic impact on the city.

The limitations of few monitoring stations were overcome by using spatial interpolation techniques such as Inverse Distance Weighted interpolation technique. The performance of the interpolation was tested using cross-validation techniques and the results revealed that Bangalore city would benefit from increased measuring stations for PM_{10}. *The logistic regression conducted showed that pollution especially* PM_{10} *was a likely predictor of CVD in the city. Spatial analysis was conducted and included buffering, overlay maps, queries and Hotspot analysis highlighting the zone hotspots.*

The results from the research guided the development of the novel 5-I model that would assist other similar developing cities to assess the effects of air pollution on CVD. The impetus is that based on evidence, intervention policies and programs may be implemented to inform research and practice which will ultimately have social, economic and health impact on the population. On implementation of the model, hotspots will be identified in order to roll out interventions to priority areas and populations most at risk that will ultimately prevent millions of deaths and enhance overall quality of life.

Coventry University

Dedication

To Mum and Dad

I am who I am today only because of your love, encouragement and your incessant belief in me. I immensely appreciate your sacrifices – I wouldn't have gotten this far without you.

To Kumar

For your unending support, relentless positivity and boundless inspiration: You are my rock.

To Karthik and Vignesh

For your patience, sacrifice, selfless-love, cuddles and kisses; mostly for being such wonderful, lovely boys – you are a true blessing.

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Contents

List of Figures

List of Tables

List of Abbreviations

AP	Air Pollution
BBMP	Bruhat Bangalore Mahanagara Palike
BP	Blood Pressure
CVD	Cardiovascular Disease
DALY	Disability Adjusted Life Years
DES	Directorate of Economics and Statistics
ENVHIS	Environmental Health Information System
GDP	Gross Domestic Product
GIS	Geographical Information System
HDL	High Density Lipoprotein
IHD	Ischaemic Heart Disease
ITCP	International Tobacco Control Project
LDL	Low Density Lipoprotein
MCCD	Medically Certified Cause of Death
NO_x	Oxides of Nitrogen
O_3	Ozone
PM	Particulate Matter
RHD	Rheumatic Heart Disease
SO_2	Sulphur dioxide
SPSS	Statistical Package for the Social Sciences
WHF	World Heart Federation
WHO	World Health Organization

List of Publications

This research has been documented, in part, within the following publications:

Chinnaswamy AK, Balisane H, Nguyen QT, Naguib RNG, Trodd N, Marshall IM, Yaacob N, Santos GN, Vallar EA, Galvez MC, Shaker MH, Wickramasinghe N and Ton TN. Data Quality Issues in the GIS Modelling of Air Pollution and Cardiovascular Mortality in Bangalore. International Journal of Information Quality, 2015: volume 4 (1): 64-81

Chinnaswamy AK, Galvez MC, Balisane H, Nguyen QT, Naguib RNG, Trodd N, Marshall IM, Yaacob N, Santos GN, Vallar EA, Shaker MH, Wickramasinghe N and Ton TN. Air Pollution in Bangalore, India: A Six-Year Trend Analysis and Spatial-Temporal Variations using Geostatistical Techniques. Int. J. Environmental Technology and Management, 2015: (submitted January 15).

Chinnaswamy AK, Naguib RNG, Nguyen QT, Marshall IM, Yaacob N, Santos GN, Vallar EA, Galvez MC, Shaker MH and Ton TN. Air Pollution in Bangalore, India: A Six-Year Trend and Health Implication Analysis. Proc. IEEE Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, Puerto Princesa, Philippines, 2014 (CD-ROM).

Chinnaswamy AK, Naguib RNG, Nguyen QT, Marshall IM, Yaacob N, Santos GN, Vallar EA, Galvez MC, Shaker MH and Ton TN. Spatio-Temporal Analysis of the Effects of Air Pollution Hazards on Cardiovascular Health Outcomes in Bangalore, India. Proc. IEEE Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, Puerto Princesa, Philippines, 2014 (CD-ROM).

Chinnaswamy AK, Naguib RNG, Nguyen QT, Marshall IM, Yaacob N, Santos GN, Vallar EA, Galvez MC, Shaker MH and Ton TN. Spatial Interpolation of Air Pollutants in Bangalore: 2010-2013. Proc. IEEE Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, Puerto Princesa, Philippines, 2014 (CD-ROM).

Chinnaswamy AK, Naguib RNG, Olayanju LO, Nguyen QT, Bali RK, Marshall IM and Shaker MH. Association Between Outdoor Air Pollution and Cardiovascular Mortality in Bangalore. Proc. IEEE Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, Manila, Philippines, 2013: 31.

Chapter 1: Introduction

1.1 Overview

Cardiovascular Disease (CVD) is the world's leading cause of death. Approximately 80% of all cardiovascular-related deaths however occur in low- and middle-income countries and at a younger age in comparison to high income countries (Gersh *et al*. 2010). Countries in Asia such as China and India, particularly, are burdened by the disease. In India, 41% of urban male deaths and 37% of urban female deaths were reported to be due to CVDs (Celermajer *et al*. 2012).

The main determinants of CVD, until recently, included lifestyle factors, diet, health history, hereditary factors, smoking and alcohol consumption. Over the last decade, studies have emerged, particularly in the developed nations that include air pollution (AP) as a determinant for CVD. Air pollution is increasingly becoming a global concern and is believed to be amongst the leading causes of death in the world today. The World Health Organization (WHO) estimates that 2 million people die prematurely due to air pollution (WHO 2011a). Developed countries have recognised air pollution as a major public health concern and have developed strategies to effectively tackle it and improve air quality. However, air pollution in developing countries and particularly in Asian cities, is relatively high when compared to cities of the developed world (Schwela *et al*. 2006). The levels of air pollution in these cities regularly exceed WHO recommended guidelines with smoke and dust particles being double the world average (Schwela *et al*. 2006). Delhi, the capital city of India, is the highest polluted city in the world (The Indian Express 2014). The common air pollutants such as NO_x, O_3 and PM are a significant challenge in Asian cities. Furthermore, it has been established that 13 of the world's top 20 polluted cities are in India, followed by cities in Pakistan and Bangladesh (Roychoudhury 2014).

Several epidemiological studies that include long- and short-term studies have produced a positive and statistically significant association between high levels of pollution and occurrences of cardiovascular diseases, most of which emerge from developed countries. Although research already exists in developed nations, it is not viable to use the findings as inferences for developing nations due to the apparent differences in the sources of pollution, living conditions, lifestyles and quality of healthcare delivery. Hence, there is a growing need to understand the magnitude of air pollution and the patterns of cardiovascular diseases in developing countries, especially in urban populations and there is an urgent need to fill the knowledge gap of the impact of air pollution and CVD in Asia. This research aims to contribute to this gap in knowledge.

1.2 Problem Statement

There are limited studies emerging from Asia discussing the harmful effects of air pollution on CVD. Su *et al*. (2011) reviewed the scientific literature on air pollution and CVD published by Asian researchers since the 1980s. They determined that the findings in Europe and North America cannot be extrapolated to Asia and state that multi-country epidemiological studies are needed to fully appreciate the extent of air pollution on CVD in Asia and especially in less developed Asian countries. On reviewing the references in the American Heart Association statement, they determined that only 10% of the references are from Asia, of which most addressed respiratory outcomes. There were only about 50 studies that evaluated CVD outcomes in Asia, a high percentage of which emerge from Japan, South Korea, Taiwan, China and Hong Kong.

Yamamoto *et al*. (2014) assessed the evidence that included the available peer-reviewed empirical studies in English on air pollution and its effects on CVD. They focused on countries in South Asia such as India, Afghanistan, Bangladesh, Maldives, Bhutan, Nepal, Pakistan and Sri Lanka between the years 1990-2012. They determined that only nine articles met their inclusion criteria, most of which were from the North and West India and one article from Pakistan. Among these studies, cross-sectional, time series and case-crossover designs were commonly used, most of which were short-term studies. With the increasing air pollution problem in Asia, Yamomoto *et al*. (2014) state that there is an urgent need for studies in these cities.

Apart from the lack of research output, there is also a lack of awareness in these countries of the harmful effects of pollution on CVD. Studies in Asia that assessed the awareness of cardiologists' knowledge on air pollution and CVD revealed that cardiologists are not yet fully aware of such associations and do not include them in their clinical practice (Nguyen 2011; Su *et al*. 2011).

There are other major factors as illustrated in Figure 1.1 that are likely to hinder research in developing countries:

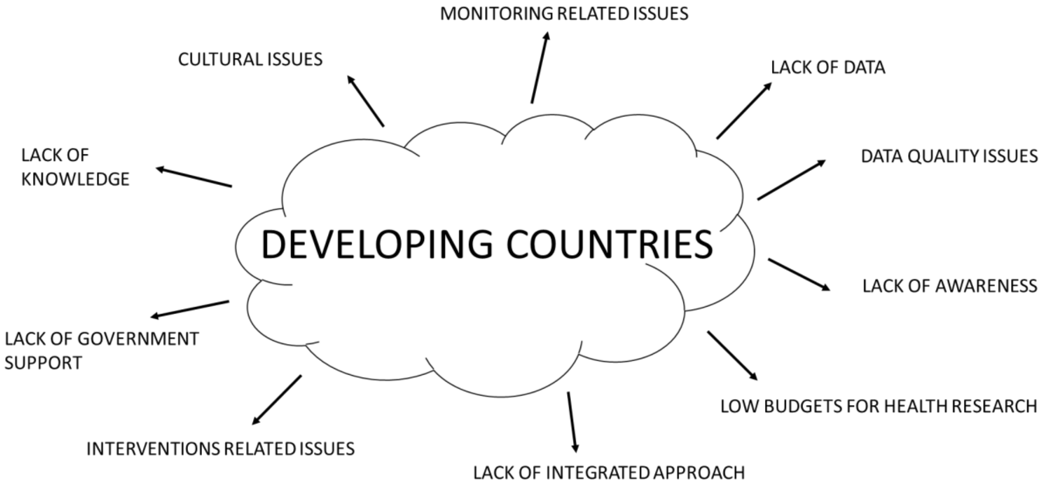

Figure 1.1: Issues in Developing Countries

These barriers appear to hinder valuable research that could ultimately contribute to health and well-being, this study investigates these barriers. As the spatial location plays a vital role in the health and well-being of a person, this research proposes the use of a spatiotemporal methodology to assess the effects of air pollution on CVD. It also assesses the processes used for data collection, the quality of the data, and the shortcomings in the data. A data quality framework based on WHO guidelines and which is generalisable for cities/countries with similar data quality limitations is developed. Based on a Geographical Information System (GIS) an environmental health information system is developed that will assist in addressing the challenges posed by air pollution and CVD in developing cities. The research process results in the development of a novel model that guides strengthening systems and practice to assist in targeting interventions at areas and populations at risk and also facilitate future research This will result in informing research and practice, to improve communication between stakeholders, encourage integrated working and the development of policies that will prevent the onset or exacerbation of air-pollution induced CVDs and improve overall quality of life.

1.3 Research Question

This can be encapsulated in the following:
"Can a novel model of health information system strengthen process for conducting research to understand the effects of air pollution on CVD in developing countries?"

1.4 Research Aim and Objectives

The aim of this study is to design, develop and evaluate an environmental health information system model that will strengthen processes to support the spatiotemporal analysis of the effects of air pollution on CVD in developing countries.

To achieve this aim, the objectives of this study are to:

- Explore the CVD and Air Pollution background in a case study of Bangalore, identify specific barriers and investigate the data collection processes to assess any limitations;
- Develop an application to be used on a GIS platform that supports spatiotemporal analysis of the effects of air pollution on CVD in Bangalore;
- Develop a Data Quality framework that recommends procedures to improve data quality in Bangalore;
- Demonstrate the analysis of CVD mortality and concentrations of PM_{10}, SO_2 and NO_x to determine hotspots in Bangalore;
- Use the research carried out in Bangalore, develop and evaluate a generalisable empirical model that could, using existing topographic, environmental, demographic and health records, strengthen decision-making in healthcare management in developing regions with incomplete monitoring and with data quality issues.

1.5 General Methodology

1.5.1 Background

In order to develop a model to assess the effects of air pollution on CVD in developing countries, a case study area is sought that is a good representative of the rapidly growing cities in the developing world. It is essential that the selected case reflects the characteristics and problems identified in the underlying theoretical propositions.

Bangalore city was selected as the case study area because it is one of the fastest growing economies in India, the opportunities the city offers as a result of this economic development has led to a significant growth in population. The infrastructure, transport and other amenities are insufficient to address this rapid growth and the city is witnessing congestion, high levels of pollution, deteriorating health, etc. Bangalore is a good representative of rapidly growing cities in developing countries.

Although the impact of the air problem in Bangalore is acknowledged by government officials, there is lack of an evidence base to highlight the city's health scenario. The recent wealth of research that highlights the link between air pollutants and CVD is clearly absent in the city and Bangalore would certainly benefit from a research study that integrates data from the various departments.

1.5.2 Spatiotemporal Methodology

Having assessed the studies of air pollution and CVD in developed countries, it was determined that most studies utilised methodologies that were traditional statistics, meta-analysis, etc. The methodologies also assumed that the data was collected routinely and timeously. The methodologies did not allow for options where data collection may be sparse and incomplete.

It is well documented that geography plays an important role in understanding the dynamics of health and the causes and spread of disease and where a person lives determines their well-being. Geographical epidemiology is an effective tool to describe and analyse disease clustering correlated with demographic, environmental, behavioural, socio-economic, genetic and infectious risk factors. Based on this premise, this research proposes the use of a spatiotemporal methodology to assess the relationship between air pollution variables and mortality trends over a period of time. A GIS based environment health information system is developed to identify the geographical distribution and variation in disease, correlate spatial and temporal trends of disease and air pollution and map populations at risk.

The proposed GIS environmental health system approach therefore integrates all of the temporal and spatial information to analyse and produce visualised tools, which facilitates greater communication (ALGA 2007). Consequently, this will allow policy makers to envisage the information described and thereby formulate more informed decisions. The proposed approach will incorporate the following:

- The development and use of an approach to enhance air pollution and CVD activities;
- Allow various sets of information to be integrated and analysed for the abatement of the influence of pollutants on CVD;
- Make use of existing datasets and use technology to assist in the awareness of CVD and the confounding factors;
- Provide a graphical representation of the spread of pollutants and any CVD clusters;
- Promote collaboration and learning;
- Inform policy and advocacy;
- Improve programmes, practice, and research;
- Enhance health training and education programmes;
- Increase awareness;
- Propose interventions leading to an enhanced quality of life.

1.6 Overview of Research Activities

The purpose and aim of this study dictates its research strategy and the phases. The objectives determine how the research is to be approached and set the key tasks to meet the goals of the project. The research framework in Figure 1.2 provides the logical sequence of the different phases in the conception of this research project. The overall research is distinctively categorised into four phases of study and are described as:

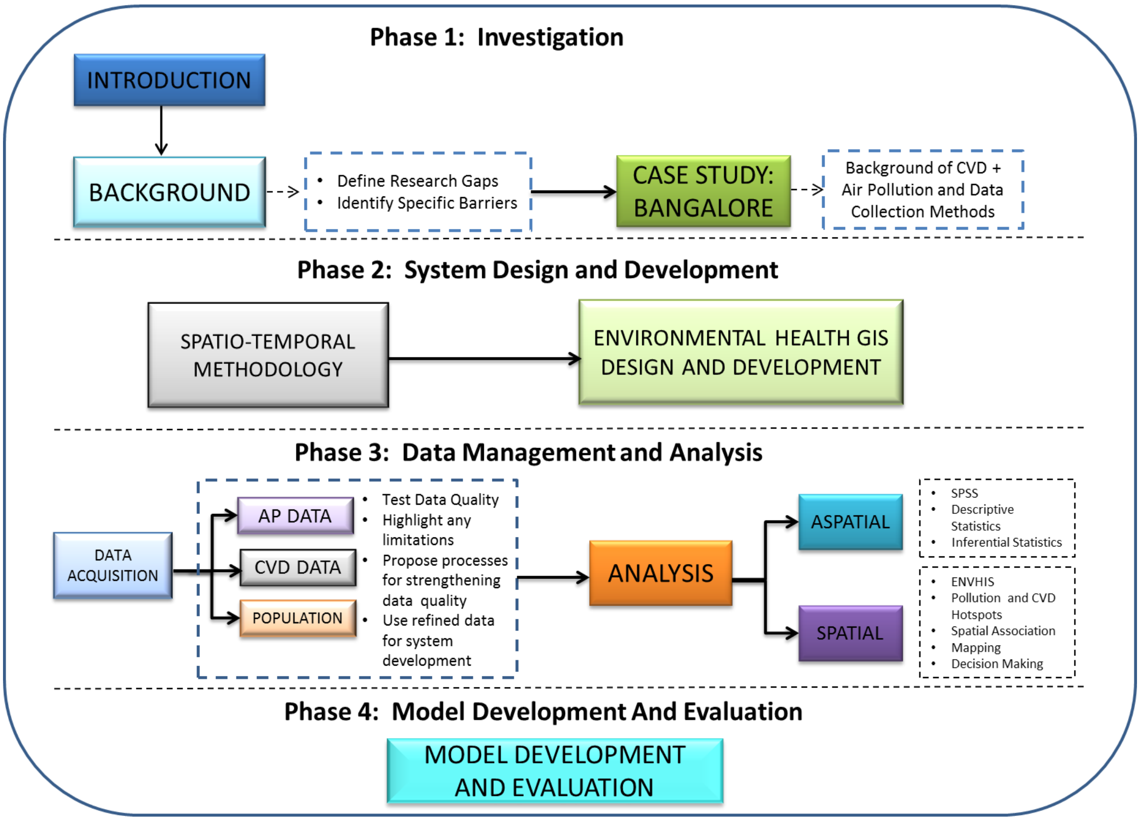

Figure 1.2: Research Stages

Having identified and defined the phases of the study, the next step was to define the tasks undertaken in each phase. The research map in Table 1.1 (page 10) provides an overview of the research approach, defining the phases of the research project, provides the corresponding objectives for the particular phase, the key tasks that are undertaken for each of the objectives and also the research method to execute the tasks.

1.6.1 Phase 1: Investigation

The goal of the investigation phase was to provide an understanding of the CVD scenario and also the data collection strategies in the case study area. The background of air pollution is explored, the air quality monitoring methods in the city is investigated and the air pollution data is discussed.

1.6.2 Phase 2: System Development and Analysis

This phase consists of the design and development of an Environmental Health Information System (ENVHIS) that will support the spatiotemporal analysis of the effects of air pollution on CVD. This GIS based system was used to integrate the datasets, provide various spatial analyses, determine hotspots and provide as a tool that will support in the decision making process.

1.6.3 Phase 3: Data Management and Analysis

The design of this research relied heavily on data from secondary sources that had to be acquired, gathered and integrated to reach a holistic understanding of the phenomenon under study. According to Baxter and Jack (2008), each data source is one piece of a puzzle, with each piece contributing to the researcher's understanding of the whole phenomenon.

This research used secondary data and, within certain limitations, the maxim would apply that the more data the better. The research acquired large amounts of data from a wide variety of sources in a huge array of formats. The collection of these overwhelming amounts of data required appropriate management and analysis.

The data for this research was classified both as spatial data and non-spatial data. As the spatiotemporal methodology required the geography of the case study area, the base maps of the region depicting land use, boundaries, zones, major roads and thematic maps were acquired. Non-spatial data such as zonal population data, levels of air pollution over a period of time and for various pollutants were obtained. The cardiovascular health data for the region was also obtained.

To handle the large amounts of data, data management systems such as spreadsheets, databases and graphics packages, were used to clean up and store the data. The data was then processed by detecting and correcting inaccurate records. The datasets acquired were then subject to testing for data quality parameters such as completeness, accuracy, objectivity, etc. Once the data was tested for quality, the limitations were highlighted and a framework was developed for improving the data quality.

Analysis of the data is performed in 2 ways:

- Aspatial Analysis
- Spatial Analysis

Aspatial analysis was carried out using SPSS, a Windows based program that can be used to perform data entry and analysis and to create tables and graphs. SPSS is capable of handling large amounts of data and can perform a wide variety of statistics; allowing descriptive and inferential analysis to be carried out on the datasets.

Spatial analysis included a set of techniques that determine relationships between various spatial and non-spatial factors and included buffer analysis, overlay analysis, geocoding, spatial interpolation and determination of hotspots.

1.6.4 Phase 4: Model Development and Validation

The results and findings of the research guided the development of a novel model that aims to assist in tackling effects of air pollution on CVD in developing cities. The model was validated by stakeholders; who are key decision-makers in governmental departments that include health, environment, road and traffic management and infrastructure policy-making. The key objectives of the validation process were to ensure that the model addressed the empirical gaps in research, reduced knowledge isolation, assisted in policy planning and interventions and integrates information sharing and knowledge transformation among stakeholders.

Table 1.1: Research Map

PHASE	OBJECTIVES	KEY TASKS	METHOD
Phase 1 Investigation	Explore the CVD and Air Pollution background in a case study of Bangalore, identify specific barriers and investigate the data collection processes to assess any limitations	• Explore CVD scenario in case study area • Explore air pollution scenario in case study area • Explore CVD data collection methods and data • Explore air pollution data collection methods and data	Literature Review Case Study Quantitative Methods
Phase 2 Design and Development	Design a GIS based system that supports spatiotemporal analysis of the effects of air pollution on CVD in Bangalore	• Design a GIS based system application	System Design and Development
Phase 3 Data Management and Analysis	Develop a Data Quality Framework that recommends procedures to improve data quality in Bangalore	• Collect data from various stakeholders • Discuss the quality of data obtained and the limitations associated with the data	Framework Development
	Demonstrate the analysis of CVD mortality and concentrations of PM_{10}, SO_2 and NO_x to determine hotspots in Bangalore	• Spatial analysis • Aspatial Analysis	Quantitative and Spatial Analysis
Phase 4 Model Development and Evaluation	Use the research carried out in Bangalore, develop and evaluate a generalisable empirical model that could, using existing topographic, environmental, demographic and health records, strengthen decision-making in healthcare management in developing regions with incomplete monitoring and with data quality issues	• Model Development • Validation	Framework Development Evaluation

1.7 Ethical Considerations

This research was conducted in such a way to protect ethical rights of the participants. Although an ethical form provided by the university was submitted, a summary of the ethical and moral issues considered are as follows:

- The anonymity of individuals, roles and incidents in the research was protected
- The right to privacy and confidentiality of the organisation and the individuals participating in the study was respected
- Permission to use the name of the data providers in the study was obtained
- All Data Protection principles were followed as appropriate
- Ethics approval form attached in Appendix 5

1.8 Structure of the Thesis

This thesis is structured into eight chapters, each focusing on different aspects of the research. The following is a brief summary of the contents of each chapter.

Chapter 1: introduces the research problem and the rationale for the study along with the aims and objectives of the study. It also provides the research methodology adopted for this research. The chapter also describes the structure of the thesis.

Chapter 2: is the literature review that investigates CVD, its types, the risk factors that contribute to CVD in the context of developing countries, focussing on the CVD scenario in Bangalore. The data collection methods for CVD data in Bangalore are explored and the statistics of CVD in the city are discussed. Any limitations in data are highlighted.

Chapter 3: is the literature review that investigates air pollution, the types of pollutants, sources of pollution and the effects of pollution on health. The investigation also includes the air pollution scenario in Bangalore, the air quality management and data collection methods in the city. The trends of air pollution levels in the city are explored. Any limitations in data are highlighted.

Chapter 4: provides a brief background on GIS and its benefits. It discusses the development of an Environmental Health Information System (ENVHIS) and its main components. The data requirements of the system, methods of data collection, the datasets, datatypes and the key variables of the data are described. Data modelling techniques that include the conceptual, logical and physical modelling levels are explored.

Chapter 5: discusses the datasets. Any limitations on the three datasets i.e. demographic data, CVD mortality data and air pollution data is highlighted in this section. A data quality framework is provided that will enable stakeholders in a developing city to focus on the required areas for improvement.

Chapter 6: demonstrates the analysis including non-spatial analysis using SPSS and **s**patial analysis using the ENVHIS on the datasets.

Chapter 7: presents the development of a novel model and its components. An introduction to the current gaps that defined the model process is provided. Stakeholders from key governmental departments are identified and a questionnaire developed is provided to them to receive feedback and evaluation of the model. A discussion of the feedback received from the stakeholders is conducted. Based on the responses received a summary of the consideration of the views and recommendations is provided.

Chapter 8: is the concluding chapter and it summarises the research study providing all the accomplishments of the study. It identifies the significance of the study and the novel contributions to knowledge. Limitations of the study and the future work are also described in this chapter.

Chapter 2: Cardiovascular Disease - Literature Review and Related Issues in India and Bangalore

2.1 Overview

Non-communicable disease is rising at an alarming rate with many lives lost to chronic diseases such as heart disease, stroke, diabetes, cancer and chronic respiratory disease. Of all the non-communicable diseases, globally, CVD contribute to the largest cause of mortality. This chapter provides a brief background of CVD and its impacts on India. The CVD statistics in Bangalore are presented after discussing the data collection methods in the city for CVD morbidity and mortality. The types of CVD and their risk factors are also briefly explored.

2.2 Cardiovascular Disease

CVDs are a group of disorders of the heart and blood vessels. According to the WHO (2011b), an estimated 17.3 million people per year worldwide die of CVD. The WHO also estimates that by 2030, the number of deaths due to CVD will increase to 23.6 million people and hence will remain the single leading cause of death globally (WHO 2013). CVD accounts for 3 times more deaths than those by infectious diseases, including HIV/AIDS, tuberculosis and malaria combined (Beaglehole and Bonita 2008).

Migration to urban areas for better opportunities and quality of life has posed challenges such as inadequate infrastructure, water and air pollution and a growing health crisis. Researchers have established links between urbanisation and its effects on the occurrences of CVD (Smith *et al*. 2012). Modifiable risk factors for CVD, such as smoking, diabetes, dyslipidaemia, hypertension, obesity, poor diet and sedentary lifestyles are particularly exacerbated due to pressured urban lifestyles (WHO and UNHABITAT 2010).

2.3 CVD in India

As has been mentioned earlier, cardiovascular disease is one of the world's leading causes of mortality (Ramaraj and Chellappa 2008). This is equally one of the major causes of mortality in India (Gupta *et al*., 2011) with a significant increase in cardiovascular diseases over the past decade.

A study named 'The Million Death Study' was conducted in India over the years 1998-2014 and is one of the largest studies of premature mortality in the world. It was envisaged that India like most developing countries do not have a certified cause of death, hence, a survey was designed to monitor deaths of 14 million people across the country. If the cause of death was not recorded, then a team of trained workers would determine the cause of death through Verbal Autopsy (CGHR 2015). This study was carried out with the collaboration of the Registrar General of India (RGI). A report was released from the results of this study, which stated the highest cause of mortality for all age groups, areas and genders is CVD (Table 2.1).

Table 2.1: RGI Report

RANK	ALL AGE GROUPS	RURAL	URBAN	MEN	WOMEN
1	**CVD**	**CVD**	**CVD**	**CVD**	**CVD**
2	COPD, ASTHMA	COPD, ASTHMA	CANCERS	COPD, ASTHMA	DIARRHEOA
3	DIARRHEOA	DIARRHEOA	COPD, ASTHMA	TUBERCULOSIS	COPD, ASTHMA
4	PERINATAL	PERINATAL	TUBERCULOSIS	DIARRHEOA	RESPIRATORY INFECTIONS
5	RESPIRATORY INFECTIONS	RESPIRATORY INFECTIONS	SENILITY	PERINATAL	SENILITY
6	TUBERCULOSIS	TUBERCULOSIS	DIARRHEOA	CANCERS	PERINATAL
7	CANCERS	CANCERS	INJURIES	RESPIRATORY INFECTIONS	CANCERS
8	SENILITY	SENILITY	ILL-DEFINED	INJURIES	ILL-DEFINED
9	INJURIES	INJURIES	DIGESTIVE	ILL-DEFINED	TUBERCULOSIS
10	ILL-DEFINED	ILL-DEFINED	RESPIRATORY INFECTIONS	SENILITY	INJURIES

In 1990, CVDs accounted for 63% of all deaths in India and contributed to 17% of worldwide mortality. In a study by the World Health Organisation (WHO) it was estimated that by 2010, 60% of the world's cardiac patients would be Indians (Ghaffar *et al*. 2004) and that 50% of the Indian population who die from CVD are below the age of 70 (Gaziano *et al*. 2006).

Moreover, there is scientific evidence that Indians tend to acquire the disease at least 10 years earlier than their western counterparts (Vamadevan *et al*. 2011).

India is estimated to have lost US$8.7 billion in 2005 due to affliction from CVD and diabetes (Ajay and Prabhakaran 2010), and the WHO estimates that this figure will reach US$237 billion by the end of 2015 (Goenka *et al*. 2009). Furthermore, the GDP of the country is estimated to fall by 1% due to the combined economic impacts of CVD and diabetes (Abegunde and Stanciole 2006).

2.4 Bangalore CVD Data

2.4.1 Morbidity Data

The Indian healthcare system has evolved significantly post-independence (1947) in India. The governmental health system in India is organised as a three-tier structure that focuses on promotive, preventive and curative health services. The country has implemented several National Health Programmes over the last two decades to focus on priority diseases (Ministry of Health and Family Welfare 2011).

In Bangalore, there are governmental programmes for healthcare but a large proportion of the population depends on the private health sector that mainly provides curative services for all levels of care. The healthcare provision can be defined as a mixed service since the private sector is a dominant provider of several outpatient and inpatient care services, while immunisation and several preventive health services are still largely provided by the Government services. This mixed service provision has led to a lack of integrated care with quality concerns in both sectors.

Apart from these two sectors, health services are also provided by various non-governmental organisations (NGO), charitable institutions, missions and trusts; these largely constitute the not-for-profit sectors. With no appropriate governance for all the sectors, regulation of health and its provision are poor (Sesahdri *et al*. 2013).

This has also led to health data not recorded consistently and there is substantial fragmentation of health records in the city. An attempt was made to obtain the CVD morbidity data for this research by contacting various super-speciality hospitals that specialise in CVD health. But the absence of a routine data collection method, use of paper records, no records of previous history of patients and other barriers led to the decision that this research will concentrate on the mortality data.

2.4.2 Mortality Data

According to the Registration of Births and Deaths Act 1969, in India, all births and deaths have to be reported, recorded and registered (DES 2014). Registration takes place in registration centres or hospitals. A Death Certificate is mandatory for deaths occurring outside of hospitals for issuance of a Crematorium Certificate. The head of the household, or the nearest relative, has to report the occurrence of deaths in the house, by obtaining a local doctor to certify the cause of death. In case of deaths in a hospital, the Medical Officer in charge or any authorised person is responsible for registering the death and reporting it to the local registration centre, these deaths are classified as Medically Certified Cause of Death (MCCD).

The death is recorded on the prescribed forms: Form No.4 for Hospital Deaths and Form No. 4A for Non-Institutional Deaths. This is then forwarded to the Registry of Births and Deaths which then forwards it to the Chief Registrar Office for tabulation. The data are collated and stored according to gender, age and cause of death for every year (DES 2014). Figure 2.1 provides a schematic representation of the death registration process in Bangalore.

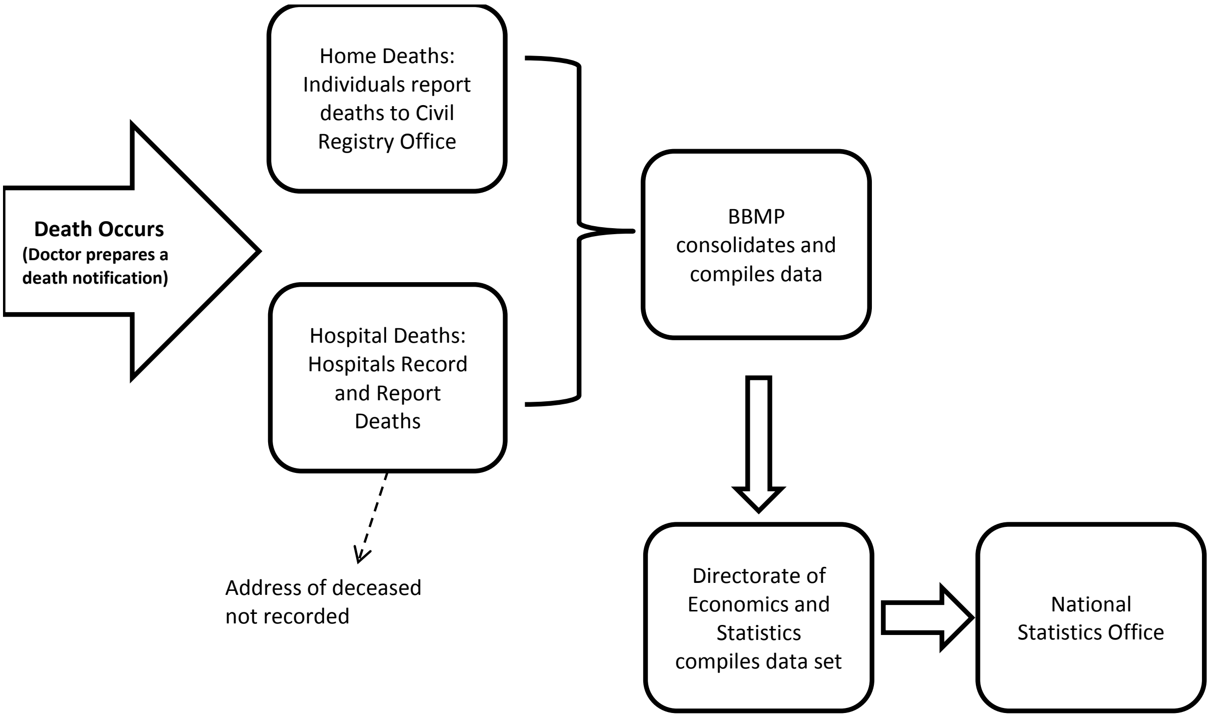

Figure 2.1: Schematic Representation of the Death Registration Process in Bangalore.

Directorate of Economics and Statistics (DES) collect the MCCD data from BBMP in Bangalore and report the mortality statistics. DES classifies data according to the ICD-10 classification for diseases that range from A00-Z99, CVD deaths range from I00-I99 in the following groups:

- I00–I09 Rheumatic heart diseases
- I10–I15 Hypertensive diseases
- I20–I25 Ischemic heart diseases
- I26–I51 Pulmonary heart disease and diseases of pulmonary circulation
- I30–I52 Other forms of heart disease
- I60–I69 Cerebrovascular diseases
- I70–I99 Other diseases of the circulatory system

2.5 CVD Statistics – Bangalore

The mortality data was obtained from the DES, Bangalore that provided the all-cause mortality for years 2006-2010. A total of 148,300 deaths were recorded for these 5 years and were grouped by age, gender and cause of death. Initial analysis of the data revealed that the CVD mortality in Bangalore contributed to 32.03% of the total MCCD mortality in 2006 and by 2010, CVD deaths contributed to 40.66% of the total MCCD deaths (Figure 2.2).

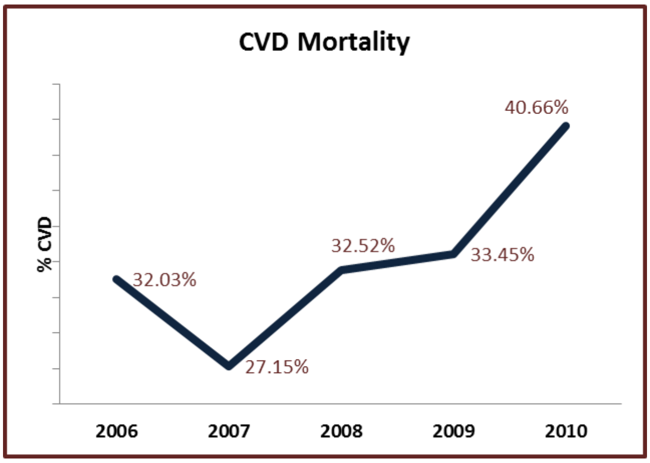

Figure 2.2: CVD Deaths

The ranking for the highest cause of mortality for 2006-2010 are represented in Table 2.2.

Table 2.2: Rank of Cause-of-Death in Bangalore

	YEAR				
RANK	2006	2007	2008	2009	2010
I	CVD	CVD	CVD	CVD	CVD
II	ENDOCRINE	INFECTIOUS	CANCERS	CANCERS	CANCERS
III	INFECTIOUS	CANCERS	ENDOCRINE	ENDOCRINE	ENDOCRINE
IV	CANCERS	ENDOCRINE	INFECTIOUS	RESPIRATORY	INFECTIOUS

Over the five years, CVD consistently was the highest cause of mortality, with cancer slowly gaining as the second leading cause of mortality. This is reflective of the shift in the health burden of the city from communicable to non-communicable diseases.

2.5.1 Data on Types of CVD

This section discusses the distribution of the types of CVD in Bangalore. Figure 2.3 represents the distribution of the types of CVD.

2.5.1.1 Ischaemic Heart Disease

Ischaemic Heart disease (IHD) also known as Coronary Heart Disease occurs when the heart's blood supply is blocked or interrupted by a build-up of fatty substances in the coronary arteries (NHS 2014). IHD constituted the highest proportion of deaths accounting to 48% of the total CVD in Bangalore, becoming the leading type of CVD in the city.

2.5.1.2 Hypertensive Heart Disease

This refers to heart conditions caused by high blood pressure (Badii 2012). Hypertensive Diseases was the second most leading cause of CVD mortality in Bangalore and contributed to 18% of the CVD deaths.

2.5.1.3 Cerebrovascular Disease

The term cerebrovascular disease includes all disorders in which an area of the brain is temporarily or permanently affected by ischemia or bleeding and one or more of the cerebral blood vessels are involved in the pathological process. Cerebrovascular disease includes stroke, carotid stenosis, vertebral stenosis and intracranial stenosis, aneurysms, and vascular malformations (AANS 2005). Cerebrovascular disease contributed to 13% of the total CVD mortality in 2006, the following years saw an increasing trend and by 2010, cerebrovascular disease contributed to 15% of total CVD mortality.

The other types of heart disease are pulmonary heart disease and rheumatic heart disease. Pulmonary Heart disease results from a lung (pulmonary) disorder. This refers to a complication of lung disorders where the blood flow into the lungs is slowed or blocked causing increased lung pressure (NHLBI 2011).

Rheumatic Heart Disease (RHD) is a chronic heart condition caused by a preceding group A streptococcal (strep) infection. Rheumatic fever that leads to RHD can be prevented and controlled (WHF 2015a). Diseases of pulmonary circulation and RHD contributed to 13% and 3% of total CVD mortality respectively.

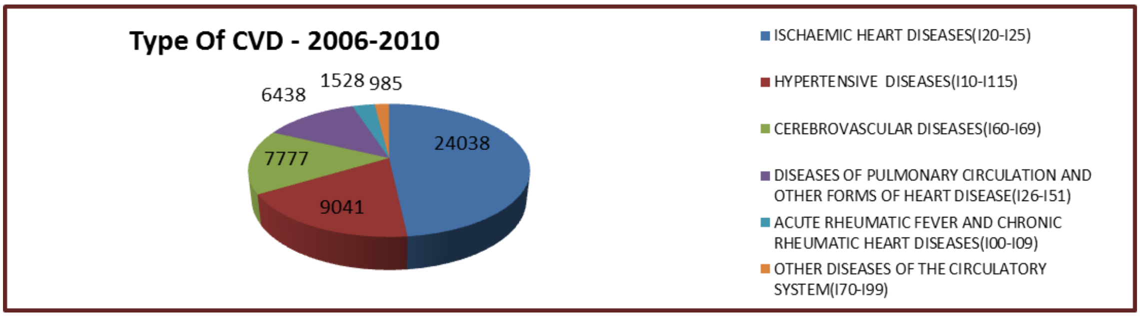

Figure 2.3: CVD Deaths over Years 2006-2010 in Bangalore

2.5.2 Risk Factors

CVD risk factors are conditions or habits that increase the chances of CVD occurrence (NHLBI, 2014) and are categorised as modifiable and non-modifiable risk factors and is illustrated in Figure 2.4. The non-modifiable risk factors include age, family history, ethnicity and gender. The modifiable risk factors are categorised into medical, behavioural and environmental factors (WHF, 2014).

The medical factors such as diabetes, hypertension, dyslipidaemia and stress can increase the risk of CVD occurrence. Behavioural factors such as tobacco use, excessive alcohol consumption, sedentary lifestyles and unhealthy diet can contribute to developing the medical factors and may directly or indirectly lead to developing CVD. There is an inter-relationship between the medical and behavioural factors for CVD i.e. as illustrated in the Figure 2.4, behavioural factors such as diet and sedentary lifestyles can lead to diabetes; medical factors such as stress scan lead to poor behavioural factors such as excessive consumption of alcohol, smoking, poor diet and sedentary lifestyles which in turn can cause hypertension, dyslipidaemia and obesity (NHS Choices, 2014). Environmental pollutants are likely predictors of CVD (Bhatnagar, 2013). All these risk factors are discussed in detail in the sections 2.5.3 and 2.5.4.

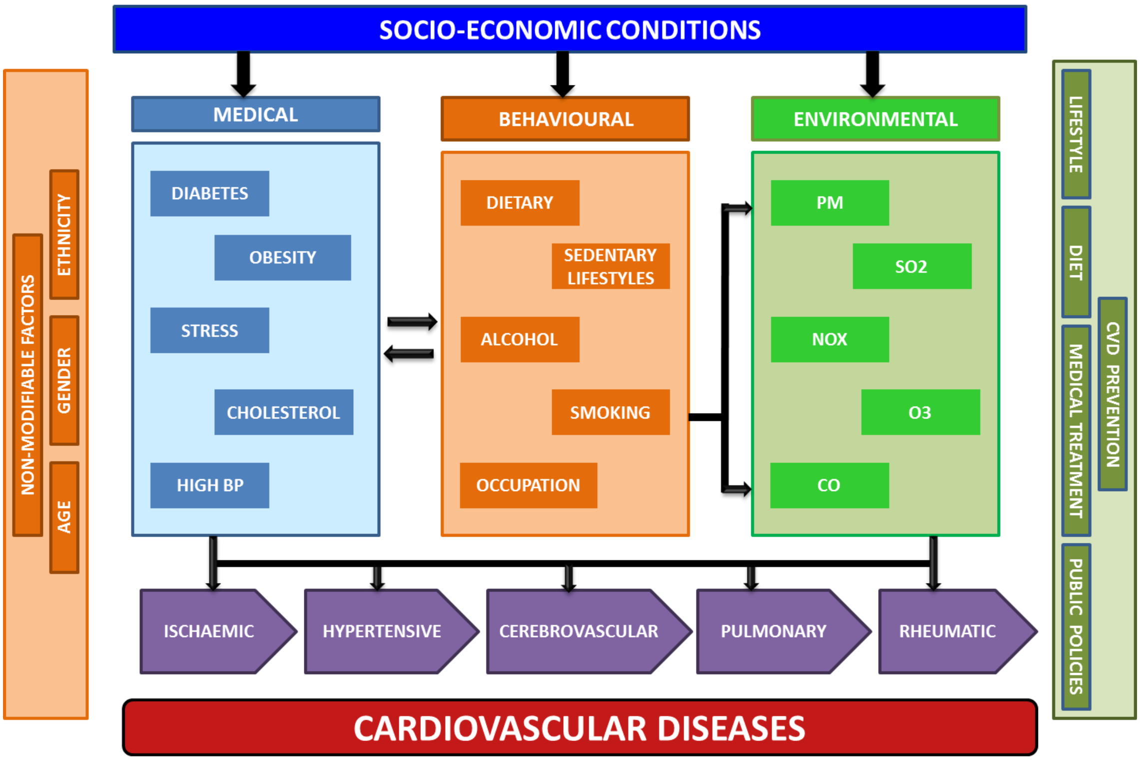

Figure 2.4: Risk Factors for CVD

2.5.3 Non-Modifiable Risk Factors

2.5.3.1 Age

Age is a non-modifiable risk factor for CVD. Although earlier CVD risk was assumed to affect older people, increasingly CVDs in low- and middle-income countries affect people at a younger age. A study of five countries that included Brazil, India, South Africa, USA and Portugal revealed that a higher proportion of deaths occurred in the working age population in Brazil, India and South Africa as compared to USA and Portugal (Leeder *et al*. 2004). It is also projected that 70% of the world's elderly live in developing countries (Gaziano 2008); this coupled with the trend towards urbanisation will result in a higher increase in CVD deaths in developing countries compared to developed countries.

In Bangalore, the highest group with CVD deaths was over 70 as illustrated in Figure 2.5. Although this demonstrates that age is an important risk factor for CVD, it is to be noted that CVD deaths under 70 in Bangalore accounted for 58% of the deaths. This is an important factor to consider as early CVD deaths result in direct and indirect costs and can have a major impact on Bangalore's economy.

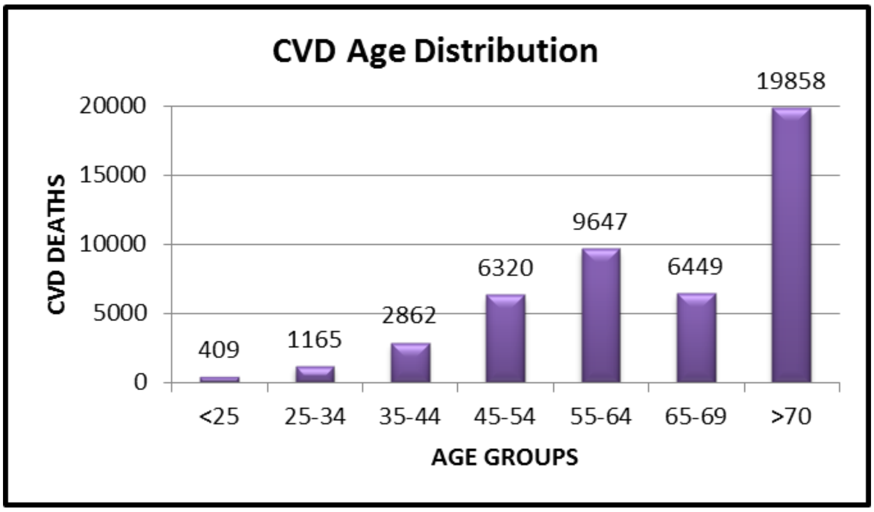

Figure 2.5: CVD Age Groups

2.5.3.2 Gender

Popular belief was that CVD affects men more than women. This led to a substantial disparity in CVD treatment between men and women. But contrary to this belief, research has demonstrated that women are equally at risk of CVD and it is the single largest cause of mortality among women (Gholizadeh 2008).

In Bangalore, males accounted for 63.5% of total CVD deaths and females contributed to 36.5% of CVD deaths. Figure 2.6 illustrates the distribution for the types of CVD mortality among men and women. Twice the number of males than females succumbed to ischaemic heart disease; approximately 60% of males and 40% of females were affected by hypertensive and pulmonary diseases. Cerebrovascular disease affected more males than females again with 67% of males and 33% of female deaths. However, Rheumatic fever affected almost equal numbers of males and females, with 51% of males succumbing to the disease and 49% of females affected by it.

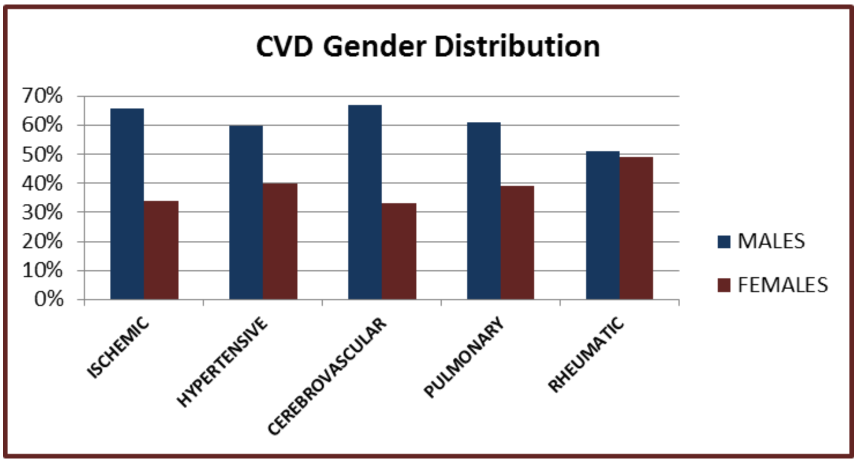

Figure 2.6: Distribution of CVD Deaths by Gender

According to Davidson *et al.* (2004), women are more likely to be influenced by socio-economic and psychological factors that contribute to CVD mortality and morbidity. Even though women share the same risk factors of CVD as men, some risk factors such as cholesterol and diabetes play greater roles in increasing the risk of CVD among women. Furthermore, women with diabetes have as much as four times higher risk of developing heart disease compared to women without diabetes (Cleveland Clinic 2014). Thus, interventions aimed at prevention of CVD have to be targeted at both the gender groups.

2.5.4 Modifiable Risk Factors

2.5.4.1 Diabetes

CVD is the leading cause of mortality for people with diabetes as it is associated with a 2-3 fold increase in risk of developing CVD (Saisho 2014). As illustrated in Figure 2.4, the behavioural factors such as unhealthy diet and sedentary lifestyles can contribute to developing diabetes (IDF, 2015). It is also usual for medical factors such as elevated blood pressure, dyslipidaemia and obesity to contribute to diabetes (NDEP 2007). The numbers of diabetics are increasing around the world and CVD remains the major cause of mortality in these patients (Seshasai 2011; Sarwar *et al*. 2010). Diabetics are 4-5 times more likely at risk of developing CVD than non-diabetics (WHF 2014); also, diabetics who smoke double their risk of developing CVD (NDEP 2007).

People with diabetes develop atherosclerosis and are more prone to hypertension. Diabetes can cause damage to the blood vessels as well as nerves, making people with diabetes more vulnerable to silent heart attacks, i.e., having a heart attack without the typically associated chest pain (WHF 2014).

Diabetes is a global healthcare problem and is projected to affect 366 million people by 2030 (Wild *et al*. 2004). The highest effect is expected to be in developing countries where 4 out of 5 people with the condition live (Haslam 2005). Asia accounts for 60% of the world's diabetics with India and China at the forefront of the current diabetes epidemic (Hu 2011). The WHO estimated that just India and China will lose national income of almost US$900 billion to diabetes. Rapid economic development, urbanisation and transition in nutritional status are all factors for this pandemic proportion of diabetes in Asia. Asians are also believed to develop the condition at a younger age than compared to their Western counterparts (Chan *et al*. 2009).

In Bangalore, over the years 2006-2010, diabetes contributed to an average of 7.82% of total mortality (Table 2.3). In 2006, approximately 10% of the deaths were due to diabetes and by 2010, 7.71% deaths were due to diabetes. More males than females succumbed to diabetes in Bangalore.

Table 2.3: Percentage of Diabetes Mortality in Bangalore

	MORTALITY - DIABETES MELLITUS				
YEAR	MALES	FEMALES	TOTAL	TOTAL MORTALITY	DIABETES MORTALITY (%)
2006	1589	1038	2627	27314	9.62%
2007	932	532	1464	22626	6.47%
2008	1468	1015	2483	31811	7.81%
2009	1515	1010	2525	33601	7.51%
2010	1504	1023	2527	32791	7.71%

The morbidity data of diabetes in Bangalore will assist in producing an exact prevalence of and provide comprehensive statistics with regards to the rate of growth of diabetes in the city. There are significant healthcare burdens to individuals, families and even societal implications due to the epidemic proportions of diabetes. It is also increasingly noted that the prevalence of the disease is occurring at relatively younger ages (Hu 2011). As diabetes is modifiable, interventions such as raising awareness, recognising contributing factors and facilitating behavioural change can mitigate the catastrophic effects and spread of the disease.

2.5.4.2 Hypertension

Elevated blood pressure, also referred to as hypertension, is the leading cause for CVD (WHF 2015b). Blood pressure (BP) is described through systolic and diastolic blood pressures. Systolic BP is the maximum pressure in the arteries when the heart contracts, whereas diastolic BP is the minimum pressure between the heart's contractions. When systolic pressure is at or above 140mmHg or diastolic pressure is at or above 90mmHg, it is referred to as hypertension (WHF 2015b). The non-modifiable risk factors for hypertension include the same as CVD such as age, family history and ethnicity. The modifiable risk factors as illustrated in Figure 2.4 include diet such as excess consumption of salt which is a significant factor for raising BP. Lack of exercise, smoking and excessive alcohol consumption can increase risk of developing hypertension. The medical factors such as obesity and diabetes can lead to high BP (NHS Choices, 2014).

Hypertension is a global problem and one of the major causes of premature deaths. There are an estimated 970 million people worldwide with hypertension, 75% of whom live in developing countries. The WHO estimates that by 2025 there will be 1.5 billion adults living with hypertension (WHO 2011c). Limited health resources and lack of awareness are some of the main reasons for poor control of blood pressure. India is said to have the highest number of people with hypertension and the prevalence increased by over 30% in just 25 years (Mayosi 2007; Padmavati 2002).

In Bangalore, Hypertensive diseases contributed to 5.24% of total mortality in the year 2006, by the year 2010, it contributed to 7.58% of total mortality (Table 2.4). More males than females were affected by hypertensive diseases.

Table 2.4: Percentage of Hypertensive Disease Mortality

	MORTALITY -HYPERTENSIVE DISEASES				
YEAR	MALES	FEMALES	TOTAL	TOTAL MORTALITY	HYPERTENSIVE DISEASE MORTALITY (%)
2006	843	587	1430	27314	5.24%
2007	700	372	1072	22626	4.74%
2008	1131	841	1972	31811	6.20%
2009	1210	871	2081	33601	6.19%
2010	1568	918	2486	32791	7.58%

Hypertension contributes to a considerable percentage of ischaemic heart disease, peripheral vascular disease, acute myocardial infarctions and strokes (Anchala 2014). There is a substantial public health burden due to hypertension, yet the awareness, treatment and control status for hypertension is low, with only half of the urban and a quarter of the rural hypertensive individuals being aware of their blood pressure status in India (Gupta 2012).

This underlines the need for an effective programme or a health information system that will result in prevention and control policies and reduce the burden of hypertension and the subsequent effects on the rising burden of CVD in Bangalore city and the country.

2.5.4.3 Cholesterol

Abnormally high levels of lipids, also commonly known as cholesterol can increase the risk of occurrence of CVD (WHF 2015c). Raised cholesterol causes atherosclerosis which is a build-up of plaque in the arteries. This causes narrowing of the arteries, slowing down the flow of blood to the heart muscle and can even cause blockages. When blood supply is cut off by a complete blockage, it results in a heart attack (WebMD 2013). The risk factors for cholesterol include smoking, obesity, poor diet, lack of exercise and diabetes (NHS Choices, 2014).

There are two types of cholesterol:

- Low Density Lipoprotein (LDL) - commonly referred to as bad cholesterol causing clogging plaque
- High Density Lipoprotein (HDL) – also referred to as good cholesterol clearing the LDL cholesterol from the arteries

Raised cholesterol is a major burden for both the developed countries as well as developing countries. Annually high levels of cholesterol cause 2.6 million deaths and 29.7 million Disability Adjusted Life Years (DALYs) (WHO 2014a). According to a study conducted by the WHO (2014), the prevalence of raised cholesterol was highest in Europe followed by the Americas. The African region and South East Asian region had lower percentages comparatively. But according to Busko (2012) elevated cholesterol was more likely among people living in countries with lower gross national incomes and inefficient healthcare system.

More than three-quarters (79%) of Indians have skewed lipid levels. Indian diet is traditionally high on carbohydrates, which have been associated with high levels of fat or triglycerides. High levels of triglycerides mean low levels of HDL, hence increasing the risk of CVD. Drug statins are available that can control the level of bad cholesterol, but only appropriate diet control and exercise can significantly boost the level of good cholesterol (Iyer 2014). There are no available studies or reports that represent Bangalore’s statistics on cholesterol.

2.5.4.4 Alcohol Consumption

One of CVD’s risk factors is excessive drinking. Although studies indicate that having one to two alcohol units a day may lead to a 20% reduction in heart disease, consumption of alcohol above this level will damage the heart muscle (Costanzo *et al*. 2010).

Alcohol abuse is emerging as a major public health concern in India, with the consumption of alcohol contributing to social, civil and domestic disturbances. India in the past had a reputation as having a culture of abstinence but is now moving towards higher levels of alcohol consumption, one of the reasons being globalisation and the impact of the western culture on the country (Prasad 2009). India was among the lowest consumers of alcohol in the world with government statistics showing only 21% of adult men and around 2% of the women as consumers of alcohol in 2009 (Prasad 2009). Certain states such as Gujarat, Manipur, Nagaland and Mizoram prohibit the sale and consumption of alcohol.

The country with its rapid economic development is also witnessing a significant shift in cultures and values. This coupled with the increasing production, promotion and easy availability of alcohol, is resulting in alcohol-related problems. Such problems are adding to the already burdened public health system in India. Surveys across the country have revealed that almost 40% of men in the age group of 15-60 years consume alcohol regularly or intermittently. These problems are beginning to be noticed across the entire country, with underage drinking (less than 21) increasing from 2% to 14% in the past 15 years (NIMHANS 2006).

Bangalore is no exception to the threat of excessive alcohol consumption, with over 800 nightclubs, pubs and lounges in the city, it is often referred to as the "Pub capital of India" (Travelnonu 2014). Moving away from a conservative society, the city now is subject to a changing pattern of alcohol consumption due to the following factors:

- Emergence of wine and beer drinking
- Increase in drinking among women
- Early experimentation and decreasing age of initiation
- Shift from urban to rural areas and transitional towns
- More "binge drinking"
- Greater acceptability of drinking as an accepted social norm
- Alcohol use combined with other high-risk behaviours

Despite the enormity of this growing concern in India, no systematic research has yet been undertaken in Bangalore to determine the levels of drinking and the effects on health (NIMHANS 2006). Awareness among the citizens and policy makers has to be raised of the harmful effects of excessive drinking on health and their potential contribution to CVD.

2.5.4.5 Tobacco

The harmful effects of tobacco use are well documented; tobacco smoking is one of the major risk factors for CVD. It is estimated that smoking contributes to 10% of CVD, with an increased risk for people who are heavy smokers and for those who started young. The risk is not only restricted to smokers but exposure to smoke is also perceived as a high risk for non-smokers. Annually, 6 million succumb to tobacco smoke, either from its use or from exposure to passive smoke. Tobacco-related deaths are projected to account for 8 million annual deaths by 2020 (Rabin and Sugarman 2001).

Tobacco smoke significantly tends to decrease the amount of oxygen that blood can carry, resulting in an increased chance of blood clots in arteries; these can consequently result in stroke or sudden death. Smoking can also damage blood vessels and raise blood pressure, all leading to a range of CVDs (WHF 2015d).

Tobacco consumption is especially increasing in developing countries with 70% of tobacco-related deaths projected to occur in these countries (MacKay and Crofton 1996). Alarmingly, half of the tobacco-related deaths will be among people in the productive ages causing a significant impact on a nation’s economy. Smoking among women is also projected to increase (Hitchman and Fong 2011).

There has been a geographical shift in tobacco use patterns: users in the West were purported to be the major users of tobacco, but in 2009, 24% of the world’s tobacco users were from the developed world and the larger 76% of users were from the developing world. This may be due to increased marketing activities by the tobacco companies and the corresponding countries' lax laws (Dugan 2011).

According to the WHO, India is home to 12% of the world’s smokers, with approximately 120 million smokers. Tobacco has a large influence in India causing a huge burden on the public health. In 2009, it was reported that approximately 900,000 people die annually in India only due to smoking, this could rise to 1.5 million annual deaths by 2020 (Kelland 2013). The statistics are such that 34.6% of men and 3.4% of women aged 18 years or above smoke across India. Also, 12.9 % of adolescents in the age group 13-15 years smoke in the country.

Smokeless tobacco, which is available as chewing products such as gutkha, zarda, paan masal and khaini are widely popular in India, with many poorer populations resorting to this form of tobacco rather than smoking cigarettes or even bidis, which are cheap locally produced cigarettes. Smokeless tobacco is known to cause oral and other cancers, as well as being a major risk factor for heart disease (Ministry of Health and Family Welfare 2010).

India has implemented several anti-tobacco and smoke-free laws and even signed a global treaty on tobacco control, but according to a report by the International Tobacco Control Project (ITCP), it is failing to implement them effectively (Kelland 2013).

The number of smokers in Bangalore has dramatically increased in the last decade with younger populations and increased female populations starting to smoke from a younger age.

Non-smokers are affected by tobacco too. Exposure to second-hand smoke can result in a 25-30% increase in the risk of developing CVD (CDC 2014). In the USA, annually, 600,000 people die from exposure to second-hand smoke (US Dept of Health and Human Services 2006), with 80% of these deaths due to CVD (Öberg *et al*. 2011). A large number of children are also affected by second-hand smoke (US Dept of Health and Human Services 2006). Other studies also demonstrated that passive smokers are at 25% excess risk of developing coronary diseases. Increased arterial thickening has been reported among passive smokers in the Atherosclerosis Risk in Community study (White *et al*. 1996).

The harmful effects of tobacco have to be communicated to the population, with an increased awareness of their hazardous effects being conveyed from a young age.

2.5.4.6 Obesity

Obesity is a term when someone is very overweight, with a lot of body fat (NHS Choices, 2014). There are several factors that can lead to obesity such as excessive consumption of calories, genetics, lifestyle, unhealthy diet and age. Obesity is a growing concern not only in developed countries but also developing countries. There are several health risks for Obesity such as Type 2 Diabetes, high BP, High triglycerides and low high-density lipoprotein (HDL) cholesterol, CVD and several types of cancer (Mayo Clinic, 2015).

India is the third most obese country in the world. According to a study of the Global Burden of Disease Study 1990-2013(Vos *et al*. 2013), data was collected in various countries for 3 decades. The USA had the highest number of obese people in the world accounting for 13%, followed by China and India (McKay 2014) (Figure 2.7). Obesity is found to be increasing in India, with the prevalence of obesity in urban areas being higher than in rural areas. The prevalence in 2006 was 28.9% in urban areas compared to 8.6% in rural areas.

India has a history of undernourishment with a high percentage of the population approximately 20% being undernourished (Bellman 2014). At the other end of the spectrum, India is witnessing a high number of obese people who have been exposed to over nutrition due to urbanisation. This is mainly due to increased consumption of processed foods that contain a significantly high percentage of trans-fat, sugar and other unhealthy and artificial ingredients (Sharma 2014).

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Figure 2.7: Obesity – Top 10 Countries (McKay 2014)

A survey conducted among 4000 residents mainly from urban cities in India determined that 73% of the respondents were overweight with more than 50% of them obese (Gupta 2013). The maximum risk age for both men and women were stated as 28-38 years (Dutta 2013).

2.5.4.7 *Diet, Nutrition and Physical Activity*

Changes in lifestyle, wealth and the availability of western style food have had a dramatic impact on the diets of children in India. Consumption of food such as burgers, pizzas and carbonated drinks are increasingly popular among school children. Exercising is not common in India, hence the increased consumption of junk food, coupled with sedentary lifestyles, is leading to an increase in obesity. Street food that is almost always fried and high in saturated fats is very popular. These energy dense foods may increase cholesterol and increase the risk of heart disease (Smith *et al*. 2012).

Although CVDs have reached epidemic proportions they could be significantly reduced through mitigation of risk factors, early detection and timely treatments (Mendis *et al*. 2011) and the past two decades have witnessed its substantial decline in high-income countries (Leeder *et al*. 2004; Reddy and Yusuf 1998; World Bank 2007).

The UK has one of the highest falling rates of CVD in all of Europe and between 1981 and 2000 has seen a dramatic decline in coronary heart disease mortality. Approximately 42% of this decrease has been attributed to treatment (including 11% to secondary prevention, 13% to heart failure treatment, 8% to initial treatment of acute myocardial infarction, and 3% to hypertension treatment). Fifty-eight percent of the decline has been attributed to population-wide risk factor reductions (Unal *et al*. 2004).

All the behavioural risk factors i.e. excessive alcohol consumption, smoking, obesity, unhealthy eating and sedentary lifestyles discussed can to a large extent be controlled or prevented by adopting healthier lifestyles, diet and exercise. It has been demonstrated that interventions focussed on population-wide primary prevention and individual healthcare has contributed to a decline in mortality trends and improved survival rates after cardiovascular events (Suhrcke *et al*. 2012; Otgontuya *et al*. 2012).

There has been no systemic research yet conducted in Bangalore that surveys these risk factors and their prevalence.

2.6 Summary

The CVD mortality statistics in Bangalore city have been discussed with data obtained from DES. The risk factors for CVD are discussed in this chapter, but there is no routine data available in Bangalore or any surveys carried out that determines the extent of the behavioural risk factors. Routinely collected data can assist in identification of any clustering of these risk factors and administer prevention measures.

Environmental pollution as a risk factor for CVD has only been considered in the last decade and research started focussing on the hazardous effects of pollutants such as SO_2, NO_x and PM on CVD (Bhatnagar 2011). The following chapter will explore air pollution, its effects on health and how it affects CVD.

Chapter 3: Air Pollution - Literature Review and Related Issues in India and Bangalore

3.1 Overview

Air pollution is the 13th leading cause of mortality and urban air pollution, in particular, affects the health and well-being of millions of people around the world. The WHO estimates that as many as 1.4 billion urban residents in the developing world breathe air pollutant concentrations exceeding their guideline values (WHO 2002).

A 2007 WHO report stated that there are huge inequalities in the impact on health due to environmental factors. Furthermore, the report demonstrated that public health can be improved through the reduction of environmental threats such as pollution and climate changes (Prüss-Üstün and Corvalán 2006). This report revealed that, globally, up to 13 million deaths could be averted annually through better environmental management; this would result in the prevention of over 30% of the disease burden. The WHO states that air pollution attributed to premature deaths of over 2 million, half of these deaths borne by the population in developing countries (Prüss-Üstün and Corvalán 2006).

The lack of research output from developed countries has resulted in these countries relying on research conducted in the developed world, especially North America and Europe. Although the characteristics of the ambient pollutants and the environmental conditions differ in these countries, the estimates of air pollution and the subsequent health effects are extrapolated. Furthermore, there is a wide disparity in the prevailing health conditions of the population in developing countries and the developed countries that influence the health outcomes differently (Omanga *et al*. 2014).

This chapter will discuss the background of air pollution in Bangalore, the sources of pollution, its effects on health, and the air pollution trend in the city.

3.2 Introduction

Air comprises natural gases and mainly consists of Nitrogen, Oxygen, Argon, Carbon Dioxide and a small amount of other gases (Colls 2002). Proportions of molecules in clean dry air are outlined in Table 3.1.

Table 3.1: Proportions of Molecules in Dry Air (Colls 2002)

Air is said to be polluted when it is contaminated by noxious gases and minute particles of solid and liquid matter (particulates) in concentrations that endanger health. Air pollution is the introduction of substances or energy into the environment, usually by humans, that are liable to cause hazard to human health and substantially harm living resources and ecological systems (Colls 2002).

Air pollution is a complex mixture of gaseous and particulate compounds and, depending on their origins, can be classified as primary and secondary pollutants. Primary pollutants are those that are generally emitted directly into the atmosphere, whereas secondary pollution occurs due to chemical reactions that involve other pollutants. CO and SO_2 are the primary pollutants; O_3 and NO_x are the secondary air pollutants in the air. Pollutants such as PM have both primary and secondary components (Limaye and Salvi 2010).

Air pollutants result from fossil fuel combustion in motor vehicles and industrial processes, from fires and volcanoes, gas burning appliances, kerosene space heaters and tobacco smoke. Residential wood burning, coal combustion and solar radiation react with molecular oxygen to form ozone in the stratosphere. Natural processes and human activities both contribute to the formation of ozone (Limaye and Salvi 2010). Table 3.2 lists the common air pollutants and their sources.

Table 3.2: Common Air Pollutants and their Sources (Limaye and Salvi 2010; EPA 2012)

3.3 Historical Perspective of Air Pollutants

The relationship between urban air pollution and its effects on health have been known for centuries, the UK recognised air pollution as a public health burden since the 13^{th} century (Haq and Schwela 2008). The term smog, a combination of smoke and fog, was coined in 1905 (Urbinato 1994), and this became a significant problem at the height of the Industrial Revolution between the 19^{th} and 20^{th} centuries (Greater London Authority 2002). The Industrial Revolution was initially seen as a symbol of growth and prosperity and no attempts were made to mitigate any air pollution problems.

It was events such as the 1952 Great London Smog that resulted in over 12,000 premature deaths (Davis *et al*. 2002), the air pollution issues in Donora Pennsylvania in 1948 (Nemery *et al*. 2001) and the Meuse Valley episode in Belgium (Helfand *et al*. 2001) that led to the formulation of policies and regulations for air quality control in the developed countries.

As a result of these policies and regulations, air pollution is considerably controlled in developed countries. This is demonstrated by the air quality concentrations measured and reported. National Ambient Air Quality standards are set for the most hazardous high volume pollutants, called the criteria pollutants that include:

- Airborne Particles (PM)
- Sulphur oxides (SO_x)
- Carbon monoxide (CO)
- Nitrogen oxides (NO_x)
- Ozone (O_3)
- Lead (Pb)

Developed countries such as the US and the UK periodically report the levels of the criteria pollutants in the air and the amounts of emissions from various sources to analyse how they have changed over time and summarise the current status of air quality.

3.4 Health Effects of Pollutants

There are typical health effects, both short- and long-term, as a consequence of high concentrations of air pollutants. Short-term effects include irritation to the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Headaches, nausea and allergic reactions are other effects as a consequence of short-term exposure. The medical conditions of individuals with asthma and emphysema can be aggravated due to short-term air pollution (National Resources Defense Council 2011).

Long-term health effects include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver, or kidneys. Continual exposure to air pollution affects the lungs of growing children and may aggravate or complicate medical conditions in the elderly (National Resources Defense Council 2011).

3.5 Cycle of Air Pollution Problems in Developing countries

The developing countries bear the brunt of the air pollution problem in the world today. Chen and Kan (2008) state that the Environmental Kuznets Curve (EKC) can be used to study the relationship between economic development and air pollution levels. According to the EKC, air pollution is generally low during the early stages of economic development. But as economic development increases, air pollution levels increase and if no appropriate remedial actions are taken, it can even increase sharply. The air pollution concentration may be improved and controlled with better measures, awareness and policies.

3.6 Air Pollution in Bangalore

The speed of economic development has an influence on the severity of air problems in any city; this is also witnessed in Bangalore where the air quality is believed to be deteriorating (The Hindu 2005). The main sources of air pollution in Bangalore are vehicles, industries, domestic and other sources (such as the common use of diesel generators). This section discusses the major sources of air pollution in Bangalore.

3.6.1 Air pollution from Vehicular Sources

One of the major sources of urban air pollution is due to vehicles; this is also the case in Bangalore. As the population has increased in Bangalore, so has the number of vehicles. In 2008, the number of registered vehicles in Bangalore was 2.29 million, whereas in 2011 it was estimated to be about 3.88 million (Figure 3.1) (Bangalore Traffic Police 2011), i.e., a 61% increase in only 3 years. This also reflects the fact that there is approximately one vehicle for every two of Bangalore's citizens. In 2014, the number of registered vehicles increased to 5.05 million (Transport Department, Govt of Karnataka 2015).

Vehicular traffic emits common air pollutants including PM_{10}, $PM_{2.5}$, SO_x, NO_x, CO and Volatile Organic Compounds (VOC). Vehicular emissions are ground level sources and have the maximum impact on human health (Kashyap 2011) .

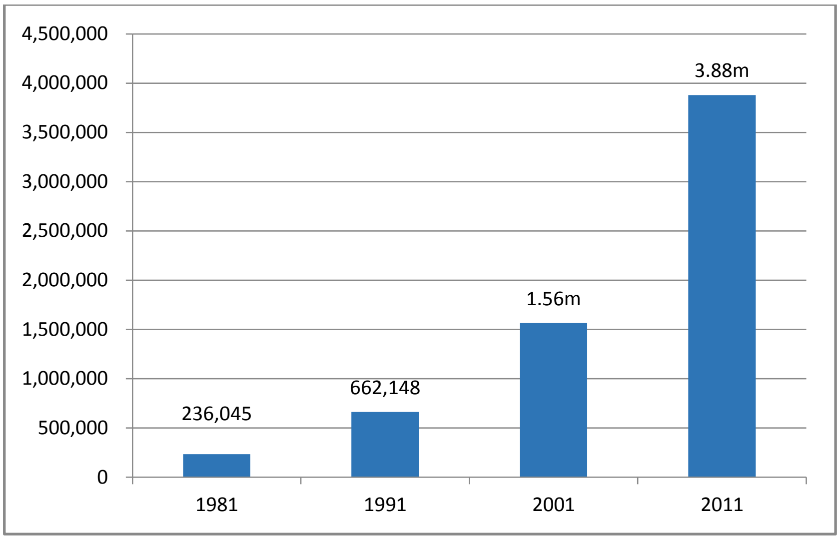

Figure 3.1: Number of Registered Motor Vehicles in Bangalore

Of the total number of registered vehicles in Bangalore, 70% are two-wheelers, 15% are cars, 4% account for auto rickshaws and 8% buses, trucks, tempos and vans. In addition, there are approximately 10,000 illegal auto rickshaws and no accurate estimate of floating traffic into and out of the city (Bangalore Traffic Police 2011).

The largest category of vehicles in Bangalore is that of two-wheelers. Most two-wheelers in India have two stroke engines, the disadvantages of such engines being that they produce more pollution as a result of the combustion of oil in the fuel. Furthermore, if the engine is badly worn, it tends to emit more oily smoke and in turn emits more pollutants into the air (Kashyap 2011).

Another important aspect is that of adulteration of fuel which, although illegal, is common practice across the city. Motorists and auto rickshaw drivers, particularly, use kerosene as it is cheaper. This not only hampers engine performance but also contributes to increased air pollution as kerosene has a high composition of VOC (Kashyap 2011).

Whilst encouraging the use of public transport may reduce air pollutants, Bangalore suffers from a poor public transport system and this has a major impetus on the use of personal vehicles. To alleviate the problems of public transport and the traffic situation in Bangalore, a Mass Transit Rail system, named 'Namma Metro' is planned, with the project having been conceived in 2003 and construction begun in 2005. The city witnessed more traffic chaos due to the construction activities, such as poor state of roads, road closures and blocks, increased dust and more people reporting respiratory problems.

Due to budgetary and management issues, the metro opening was delayed. Phase 1 opened in 2012 and Phase 2 opened in 2014. Although it was presumed to take pressure off the public transport system, it was reported that on average only 90 people travel one-way on the metro's purple line train (Phase 1 train), which has a capacity to carry 1000 passengers. In 2014, the number of commuters averaged 22,800 passengers while the Delhi metro had 2.7 million passengers. The reason for the low numbers was attributed to lack of good connectivity to all areas and problems with parking on-site at the metro station or close to it (Kidiyoor 2014).

3.6.2 Air pollution from Industrial Sources

Bangalore has a thriving economy and is a major contributor to India's economic growth. It also has a long history of industrialisation dating back to the 1920s (CPCB 2006). The headquarters of several public sector units, e.g., Hindustan Machine Tools (HMT), Bharat Electronics Ltd (BEL), Bharat Heavy Electricals Ltd (BHEL), and Indian Telephone Industries (ITI) are based in the city (Sudhira *et al.* 2007).

The city has well over 1,500 electronics and IT firms. Software related IT firms tended to locate in the vicinity of hardware units. The Department of Electronics of Karnataka State formed an 'Electronics Park', one of India's largest electronic industrial parks, in 1977 that also housed the Software Technology Park – the first in the country (Basant 2006). Bangalore also accommodates the prestigious International Technology Park Bangalore (ITPB). It is the country's first hi-tech park offering high quality infrastructure for IT and technology-related businesses (ITPB 2006).

After establishing itself as an IT hub, Bangalore has successfully attracted the biotechnology industry. As of 2004, Bangalore housed 92 of India’s 180 biotech companies. Work to set up Bangalore Helix, a 56-acre biotechnology park in Electronics City, began in 2011. Approximately 26% of the country's biotech revenue, particularly in terms of exports, is generated in Karnataka (The Economic Times 2015).

Bangalore is also a base for many important defence, space technology, aeronautics, life sciences and computer sciences industries, such as the Defence Research & Development Organisation (DRDO), Aeronautical Development Establishment (ADE), Centre for Air Borne Systems (CABS), Defence Avionics Research Establishment (DARE), Gas Turbine Research Establishment (GTRE), Centre for Artificial Intelligence & Robotics (CAIR), Electronics & Radar Development Establishment (LRDE) and Defence Bio-Engineering & Electro Medical Laboratory (DEBEL) (DRDO 2009).

The garment industry in Bangalore has about 1,200 registered companies employing over a half a million people and is one of the biggest sources of export in the country. The Doddaballapur Integrated Textile Park (DITPL) in Bangalore is one of the country's most important power loom clusters (Kumar 2010).

An important feature of the economic activities of Bangalore is the huge concentration of small- and medium-size enterprises (SMEs) in diversified sectors across the city, which has over 20 industrial estates/areas comprising such enterprises. Of these, Peenya Industrial Estate, located in the northern part of the city, comprises about 4,000 SMEs and is considered to be the largest industrial estate in South East Asia (Sudhira *et al*. 2007). Although these enterprises and industries are not as highly polluting as iron, steel or thermal power plants, they nonetheless invariably use Diesel Generator (DG) sets which contribute to high emissions of pollutants.

Moreover, as Bangalore's poor bus system is unable to cope with the demand either within the city centre or in the new outlying business districts, employees are often transported in private company coaches. This has resulted in a massive increase in the number of two-wheeler and three-wheeler vehicles, these being the most polluting forms of transport.

3.6.3 Domestic Pollution

Domestic pollution arises from different types of cooking stoves using coal, fuel wood and other biomass fuels. Poorer households in the city use inefficient and highly polluting fuels. Typical sources of domestic pollution as applicable to Bangalore include (European Environment Agency 2008; NSW Government 2012):

- Gas and paraffin heaters, stoves and cookers that produce CO;
- Gas stoves and appliances that are unflued (i.e., without a chimney);
- Household products such as cleaners;
- Beauty products (hair sprays, nail polish, perfumes, deodorants, hair dyes, soap);
- Furniture polishing substances, aerosols such as air fresheners, garden fertilisers, pesticides and insecticides;
- Soft furnishings, e.g., curtains and carpet, treated with anti-stain agents, chipboard and plywood furniture, and foam-upholstered furniture;
- Building material including paints, chipboard, floor polish and fibreglass insulation;
- Exhaust fumes entering through windows near busy roads or adjoining garages;
- Cigarette smoke;
- Allergens such as dust, pollen and mould spores;
- Bonfires, garden incinerators and barbecues.

3.6.4 Other Sources of Pollution

Bangalore is witnessing major expansion to existing roads and also construction of new roads to meet the demand in vehicle traffic. This has resulted in a number of unpaved roads in the city contributing to fugitive dust emissions. Construction materials such as sand, mud and debris are commonly found to be lying both on paved and unpaved roads. Wind and the movement of vehicles causes dispersion of these fugitive dust emissions which are major contributors of PM_{10} and $PM_{2.5}$.

Bangalore, like the rest of the nation, has frequent power outages that have resulted in the increased use of Diesel Generator sets by industries, commercial consumers and even residents. DG sets are contributors of high emissions of NO_x and SO_x. Non-point sources, such as waste burning, construction activities and roadside airborne dust due to vehicular movement also contribute to the total load of pollutant emissions.

Fireworks are a very common feature of everyday life in Bangalore, especially during festive celebrations, sporting events, weddings and even death processions. One highlight is the Festival of Light (Deepawali) which is an important occasion celebrated every year during October or November, when large quantities of fireworks are displayed. Fireworks, when burnt, can cause acute short-term air pollution through the release of various noxious gases, particulate air pollutants and toxic metals in significant quantities (Thakur *et al*. 2010).

3.7 Air Quality Monitoring

The goal of air quality management is to protect human health and the overall welfare of animal and plant life (Haq and Schwela 2008). The main objectives stated for the development of an air quality measurement system are to:

- monitor current levels;
- check the air quality relative to set standards;
- detect the importance of individual sources;
- observe any deviating trends;
- determine exposure and assess effects of air pollution on health;
- inform and raise the public's awareness about air quality;
- develop warning systems for the prediction of air pollution episodes;
- facilitate source apportionment and identification;
- supply data for research investigations;
- support legislation in relation to air quality limit values and guidelines.

In India, the Central Pollution Control Board (CPCB) coordinates the air quality monitoring network and is responsible for the country's pollution control. CPCB set the National Ambient Air Quality Monitoring Programme (NAAQM) in 1985 under the Air (prevention and control of pollution) Act, 1981. This was then amended in 1987 to provide for the prevention, control and abatement of air pollution in India. Standards were revised in 1994 and were lately revised again in 2009, introducing six new parameters. They now include NO_2, SO_2, PM_{10}, $PM_{2.5}$, O_3, CO, among other pollutants.

The standards are also based on the nature of land use, i.e., whether industrial, residential, rural or sensitive area and, in 2009, for the first time, it became mandatory for industrial areas to conform to residential zone standards (CPCB 2006). The guidelines for declaring sensitive areas as recommended by the CPCB are as follows (CPCB 2006):

- 10 km around the periphery of health resorts so notified by State Pollution Control Boards in consultation with the Department of Public Health of the concerned state;
- 10 km around the periphery of biosphere reserves, sanctities and national parks, so notified by the Ministry of Environment and Forests of the concerned state;
- 5 km around the periphery of an archaeological monument declared to be of national importance or otherwise so notified by the Archaeological Survey of India in consultation with State Pollution Control Boards;
- Areas where either delicate or sensitive (to air pollution) crops, which are important to the agriculture/horticulture of that area, are grown and so notified by State Pollution Control Boards in consultation with the Department of Agriculture/Horticulture of the concerned state;
- 5 km around the periphery of centres of tourism and/or pilgrimage due to their religious, historical, scenic or other attractions, so notified by Department of Tourism of the concerned state in consultation with State Pollution Control Boards.

Although the WHO has set air quality guidelines intended for worldwide use which are based on expert evaluation of current scientific evidence, air quality standards are also set by individual countries to protect public health. A comparison of India's revised air quality standards with those of the WHO and US-Environmental Protection Agency (EPA) are provided in Table 3.3.

Table 3.3: Comparison of India's Air Quality Standards with the WHO and US-EPA (CPCB 2009; US-EPA 2011; WHO 2006)

3.8 Karnataka State Pollution Control Board (KSPCB)

Under the NAAQM Programme, the Karnataka State Pollution Control Board (KSPCB) monitors ambient air quality in the following locations in Bangalore City (KSPCB 2014):

- Graphite India Limited, Whitefield Road
- KHB Industrial Area, Yelahanka
- Peenya Industrial area, Peenya
- Victoria Hospital, Kalasipalayam
- AMCO batteries, Mysore Road
- Yeshwanthpur Police Station, Yeshwanthpur

The KSPCB laboratories are fully equipped with experienced analysts, sophisticated equipment and approved standard test methods to carry out comprehensive analyses of ambient air. Air pollutants are measured in Bangalore by the KSPCB in the above locations with Graphite India Limited, KHB Industrial Area and Peenya Industrial Area being classified as ‘industrial areas’, while Amco Batteries and Yeshwanthpur Police Station (YPR) are classified as ‘residential areas’. Victoria hospital is the only ‘sensitive area’ location.

AMCO: is considered as mainly a residential area, but has pockets of small scale industries nearby. Highway NH-29 to Mysore lies by the factory, contributing to huge amounts of vehicular pollution.

GRAPHITE: is mainly an industrial area with pockets of residential areas in the vicinity. The locality has witnessed a huge amount of real estate activity in recent years due to the location of the world-renowned Software Technology Park (ITPL).

KHB: is an industrial area in Yelahanka New Town.

VICTORIA: is a sensitive area, however there are a large number of vehicles that ply in this area, resulting in high vehicular pollution.

YESHWANTHPUR: is considered as mainly a residential area, but has pockets of small-scale industries nearby.

PEENYA: is mainly an industrial area and is considered to be one of the largest industrial areas in Asia. Peenya lies on the Bangalore-Tumkur Highway (NH-4). It houses small, medium, and large scale industries. Table 3.4 provides the classifications and features of the monitoring stations.

Three air pollutants, namely SO_2, NO_x and PM_{10}, are regularly monitored at all locations. Respirable Suspended Particulate Matter (RSPM) generally refers to the most coarse particles of diameter size <10μm (also more commonly referred to as PM_{10}). The monitoring of pollutants is carried out for 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for PM) with a frequency of twice a week.

Table 3.4: Classification and Features of the Monitoring Stations

Air quality monitoring station	Area classification	Operating status	Height of instrument from ground level	Major sources of pollution
AMCO	Residential	Operating since 1987	7 meters above ground level	Vehicular and commercial activity
GRAPHITE	Industrial	Operating since 1987	10 meters above ground level	Vehicular, industrial & commercial activity
KHB	Industrial	Operating since 2004	3 meters above ground level	Vehicular, industrial & commercial activity
VICTORIA	Sensitive	Operating since 2004	6 meters above ground level	Vehicular and commercial activity
YESHWANTHPUR	Residential	Operating since 2004	4 meters above ground level	Vehicular, industrial & commercial activity
PEENYA	Industrial	Operating since 2004	3 meters above ground level	Vehicular, industrial & commercial activity

While selecting the sampling stations, the KSPCB gives due consideration to the following factors:

- Locate monitoring equipment on the roof of a building where continuous power supply is readily available;
- The height at the which the equipment is placed is between 3-10m above the ground so as to obtain ambient air samples not affected by local polluting factors;
- To have easy, secure accessibility to avoid any external tampering;
- To have free exposure away from tall buildings and any other obstructions.

The CPCB has established the following criteria for averaging data for ambient air quality:

- Outliers from data are removed;
- Data monitored for 16 hours or more is considered for calculating the 24-hour average;
- Days on which monitoring is carried out for less than 16 hours are not considered;
- The annual average is calculated only if data is available for 50 or more days in a year.

3.9 Sources of PM in Bangalore

The Environment and Research Institute (TERI) carried out an independent study in 2008 to prepare an inventory for different air pollutants, their emission rates and pollution loads from various sources in Bangalore. The air pollution was measured at seven sites – Domlur, Kammanahalli, Victoria Road, CSB, IGICH, Peenya and Whitefield. The sites ranged from Industrial, Residential and Sensitive. TERI established that in Bangalore SO_2 remained under recommended standards, while NO_2, PM_{10} and $PM_{2.5}$ standards were violated. The sources identified for the cause of pollution were mainly vehicle exhaust, road dust, secondary particulates, construction activities and biomass burning. The TERI study in Bangalore city showed that dust is the major source of PM_{10}. Vehicle emissions, on the other hand, are major contributors of $PM_{2.5}$. Contributions of PM_{10} from industrial and domestic sources are relatively small at only 4.5% and 4.2%, respectively. DG sets contribute significantly to PM levels – 13% for PM_{10} and nearly 25% for $PM_{2.5}$. Figure 3.2 represents the contributions of various sources of PM_{10} and $PM_{2.5}$.

The source quantification as reported by the TERI study (2010) is as follows:

- Transport sector contributes to 19% PM_{10} and 50% $PM_{2.5}$
- Share of anthropogenic sources are eclipsed by dust contributions for PM_{10}
- DG sets is an important source with contributions of 13% and 25% in PM_{10} and $PM_{2.5}$, respectively
- Contribution of industries to the particulate matter is low
- The domestic sector also has a small contribution to both PM_{10} and $PM_{2.5}$
- The share of secondary particulates is higher in $PM_{2.5}$ than in PM_{10}, depicting their finer size

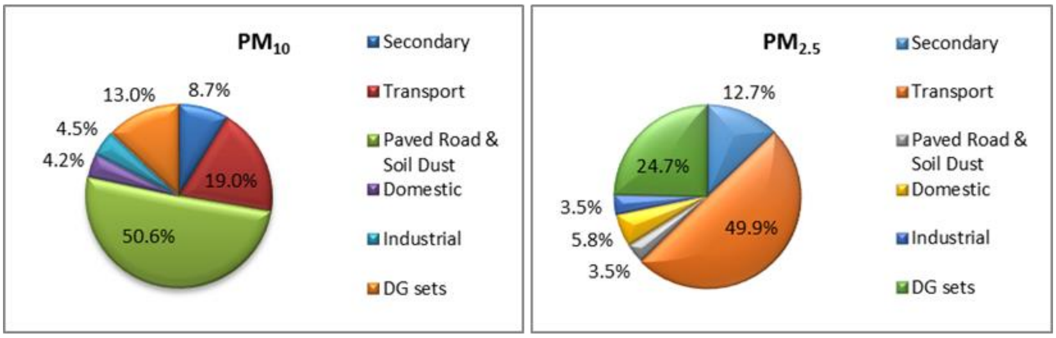

Figure 3.2: PM_{10} and $PM_{2.5}$ – Contributing Sources

3.10 Air Pollution Data

There are six fixed monitoring stations in Bangalore; the annual averages from these 6 fixed monitoring stations were obtained from the KSPCB. Data was obtained for the pollutants SO_2, NO_x and PM_{10}. Annual or decadal trends of the ambient outdoor pollutants will assist in assessing the exposure of populations and their effects on health. Hence, for this research only the data from the fixed monitoring stations are considered to determine trends.

Analysis was carried out to determine the statistics according to area and according to year as shown in Tables 3.5-3.7. Concentration ranges for the different pollutants, based on the Notification Standards and area classes described by the Central Pollution Control Board (CPCB), can be calculated through an Exceedance Factor (EF) as follows (CPCB 2010):

$$EF = \frac{\text{Observed annual mean concentration of a criterion pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

Using the above expression for EF, air pollution levels during the years 2006 to 2013 with respect to each pollutant measured is also given in Tables 3.5-3.7. CPCB (2010) states that such air pollution levels can be expressed in terms of Low, Moderate, High or Critical according to the following criteria, based on the EF of the various sites monitored:

- Critical pollution **(C):** EF > 1.5
- High pollution **(H):** EF 1.0 - 1.5
- Moderate pollution **(M)**: EF 0.5 - 1.0
- Low pollution **(L):** EF < 0.5

This section discusses the analysis of pollutants SO_2, NO_x and PM_{10} over the years 2006-2013 for the values monitored and collected from the six fixed monitoring stations.

3.10.1 Analysis of SO_2

Sulphur Dioxide [SO_2] is described as a colourless gas that is soluble having a pungent odour and taste and is said to be an irritant to the eyes, mucous membranes and the skin (Brook *et al*. 2004). SO_2 in indoor settings is usually in lower concentrations than in outdoor settings, but the use of kerosene space heaters can have a significant impact on concentrations even in indoor settings (Brook *et al*. 2004).

SO_2 is formed during the combustion of fuels containing sulphur, such as coal, and is emitted in significant quantities from thermal power plants, smelting process of sulphide ores to produce copper, lead and zinc and also petroleum refining processes. Diesel driven vehicles are specific sources of SO_2 (Rao and Rao 2005).

3.10.1.1 Effects on Health

Sulphur dioxide can aggravate existing lung diseases, especially bronchitis, wheezing, shortness of breath and coughing. It may also be responsible for increased asthma attacks, aggravation of heart and lung disease and lowered resistance to respiratory disease in children and vulnerable groups (WHO 2011a).

Studies have identified an association between SO_2 and mortality (Hedley *et al*. 2002). A study carried out in 16 Canadian cities demonstrated that SO_2 and NO_x are important risk factors for Sudden Infant Death Syndrome (Dales *et al*. 2004). SO_2 was recognised as a major health concern and policies were formulated to mitigate it. As a result, SO_2 levels have been decreasing in most parts of the world mainly due to the use of low sulphur content in fuels.

The sources of SO_2 applicable to Bangalore are mainly due to the burning of fossil fuels and diesel exhaust. As can be seen from Figure 3.3 and Table 3.5, generally the levels of SO_2 tend to be decreasing in all areas and throughout the 8 years under analysis. The percentage decrease in all the 6 areas between the years 2006-2013 was:

- Yeshwanthpur (YPR) 26.27%
- AMCO 29.25%
- Peenya 12.57%
- KHB 26.11%
- Graphite 22.33%
- Victoria 28.96%

As fuel type and quality are one of the major contributors to SO_2, the reduction may be attributed to various measures taken, such as the reduction of sulphur in diesel fuel and the wider use of liquefied petroleum gas (LPG) instead of coal as domestic fuel.

According to the WHO, a study conducted in Hong Kong in 2002 using a two-week intervention to reduce sulphur content in fuels resulted in a substantial reduction in childhood respiratory diseases, all age mortalities and related health effects over an increasingly extended period of time (Hedley *et al*. 2002). Hence, reductions in SO_2 can have significant effects on Public Health.

Figure 3.3: SO_2 levels at 6 sites in Bangalore, 2006-2013 (KSPCB 2014)

Table 3.5: SO_2 Levels, EF and Air Pollution Level Classification, 2006-2013

	YPR [RESIDENTIAL]			**AMCO [RESIDENTIAL]**			**PEENYA [INDUSTRIAL]**		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	21.7	0.43	**L**	21.2	0.42	**L**	18.3	0.37	**L**
2007	17.2	0.34	**L**	15.3	0.31	**L**	15.5	0.31	**L**
2008	16.2	0.32	**L**	15.9	0.32	**L**	16.3	0.33	**L**
2009	15.1	0.30	**L**	14.9	0.30	**L**	15.0	0.30	**L**
2010	16.3	0.33	**L**	14.2	0.28	**L**	15.4	0.31	**L**
2011	16.5	0.33	**L**	13.9	0.28	**L**	15.4	0.31	**L**
2012	12.4	0.25	**L**	16.1	0.32	**L**	15.5	0.31	**L**
2013	16.0	0.32	**L**	15.0	0.30	**L**	16.0	0.32	**L**
STANDARDS	**50**$\mu g/m^3$			**50**$\mu g/m^3$			**50**$\mu g/m^3$		
	KHB [INDUSTRIAL]			**GRAPHITE [INDUSTRIAL]**			**VICTORIA [SENSITIVE]**		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	20.3	0.41	**L**	20.6	0.41	**L**	18.3	0.92	**M**
2007	16.7	0.33	**L**	18.9	0.38	**L**	15.5	0.78	**M**
2008	15.5	0.31	**L**	16.3	0.33	**L**	16.1	0.81	**M**
2009	14.8	0.30	**L**	16.1	0.32	**L**	14.9	0.75	**M**
2010	14.6	0.29	**L**	16.5	0.33	**L**	13.3	0.67	**M**
2011	14.8	0.30	**L**	16.1	0.32	**L**	12.7	0.64	**M**
2012	17.6	0.35	**L**	19.3	0.39	**L**	12.6	0.63	**M**
2013	15.0	0.30	**L**	16.0	0.32	**L**	13.0	0.65	**M**
STANDARDS	**50**$\mu g/m^3$			**50**$\mu g/m^3$			**20**$\mu g/m^3$		

3.10.2 Analysis of NO_x

Nitrogen Oxides exist in the air (Colls 2002) as:

- Nitric Oxide [NO]
- Nitrogen dioxide [NO_2]
- Nitrogen Trioxide [NO_3]
- Nitrogen Tetroxide [N_2O_4]
- Dinitrogen Pentoxide [N_2O_5]

NO and NO_2 are artificially generated pollutants and the sum of their concentrations is referred to as Nitrogen Oxides and are expressed as NO_x. NO_x in outdoor settings results from fossil fuel combustion in motor vehicles and industrial processes, fires and volcanoes. In indoor settings, gas burning appliances, kerosene space heaters, tobacco smoke and even vehicular emissions that infiltrate indoor settings are some of the sources of NO_x (Brook *et al*. 2004).

3.10.2.1 Effects on Health

NO_x irritates the nose and throat and it appears to increase susceptibility to respiratory infections and changes in lung function, especially for asthmatics (WHO 2011a). NO_x is a pulmonary irritant and when present in excess concentration can cause pulmonary hemorrhage, chest tightness, burning of eyes, headaches and dyspnea (WHO 2011a). The European APHEA (Touloumi *et al*. 1997) and US NMMAPS (Samet *et al*. 2000) studies found significant associations between increases in nitrogen oxide levels and daily mortality. Katsouyanni *et al*. (2001) demonstrated that variations in NO_x can predict increase in daily mortality.

Figure 3.4 and Table 3.6 represent the levels of NO_x at the 6 sites under consideration in Bangalore over the years 2006-2011. As with SO_2, the levels of NO_x in Bangalore reduced in 2013 in comparison to levels in 2006. Although there were variations over the 8 years, the levels have generally remained below the recommended standard. In 2009, there was a consistent NO_x pollution level of High in all areas. In all other years the levels of NO_x was moderate. A possible explanation for the increase in trend may be attributed to vehicular number. As motor vehicle exhausts are one of the major contributors to NO_x emissions, a noticeable increase in vehicular traffic over the years 2007-09 could have contributed to the increase in levels in all areas.

The values in all areas decreased again in 2010 to achieve NO_x pollution level of Moderate. As the same combustion processes are involved, the same arguments that applied to SO_2, i.e. reduction of sulphur in diesel and wider use of liquefied petroleum gas (LPG) as fuel, would also apply to NO_x.

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Figure 3.4: NO_x Levels at 6 sites in Bangalore, 2006-2013 (KSPCB 2014)

Table 3.6: NO_x Levels, EF and Air Pollution Level Classification, 2006-2013

	YPR [RESIDENTIAL]			AMCO [RESIDENTIAL]			PEENYA [INDUSTRIAL]		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	32.1	0.80	**M**	39.1	0.98	**M**	29.6	0.74	**M**
2007	31.4	0.79	**M**	27.8	0.70	**M**	27.7	0.69	**M**
2008	39.8	1.00	**M**	38.5	0.96	**M**	39.0	0.98	**M**
2009	41.0	1.03	**H**	40.7	1.01	**H**	40.8	1.02	**H**
2010	37.2	0.93	**M**	34.5	0.86	**M**	36.4	0.91	**M**
2011	30.4	0.76	**M**	29.0	0.73	**M**	30.0	0.75	**M**
2012	32.9	0.82	**M**	31.3	0.78	**M**	28.2	0.71	**M**
2013	31.0	0.78	**M**	31.0	0.78	**M**	30.0	0.75	**M**
STANDARDS	**40**$\mu g/m^3$			**40**$\mu g/m^3$			**40**$\mu g/m^3$		
	KHB [INDUSTRIAL]			**GRAPHITE [INDUSTRIAL]**			**VICTORIA [SENSITIVE]**		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	37.3	0.93	**M**	50.7	1.27	**H**	35.7	1.19	**H**
2007	29.2	0.73	**M**	32.5	0.81	**M**	29.3	0.98	**M**
2008	39.0	0.98	**M**	40.0	1.00	**M**	38.7	1.29	**H**
2009	40.1	1.00	**H**	43.0	1.08	**H**	40.5	1.35	**H**
2010	35.6	0.89	**M**	37.9	0.95	**M**	33.4	1.11	**H**
2011	29.8	0.75	**M**	30.4	0.76	**M**	27.2	0.91	**M**
2012	32.6	0.82	**M**	30.1	0.75	**M**	28.1	0.94	**M**
2013	30.0	0.75	**M**	31.0	0.78	**M**	30.0	1.00	**M**
STANDARDS	**40**$\mu g/m^3$			**40**$\mu g/m^3$			**30**$\mu g/m^3$		

3.10.3 Analysis of PM_{10}

Airborne PM is a suspension of a heterogeneous mixture of solid and liquid particles of various sizes and chemical compositions (Brook *et al*. 2004). Particulate matter comprises primary and secondary particles. Primary particles result from direct emissions such as diesel soot into the atmosphere. Secondary particles result from a physicochemical transformation of gas such as nitrate and sulfate (Limaye and Salvi 2010). PM, due to its complex nature, is measured and regulated based on mass and has been distinguished into 3 groups based on size ranges (WHO 2013b):

- PM_{10} - <10µm in aerodynamic diameter and are referred to as thoracic particles
- $PM_{2.5}$ - <2.5µm referred to as fine particles
- $PM_{10to2.5}$ - coarse particles

Primary particulate matter consists of carbon (soot) emitted from cars, trucks, heavy equipment, burning waste, material from unpaved roads, stone crushing, construction sites and metallurgical operations. Particulate matter in urban areas is composed of carbon and hydrocarbons. A major part of particulate matter existing in the air also comes from natural sources including ground, oceans and volcanoes (Limaye and Salvi 2010). PM can travel over long distances and even remain suspended in the atmosphere over time (Kim *et al*. 2014).

3.10.3.1 Effects on Health

Particulate Matter causes a wide range of diseases and the presence of PM is said to be more dangerous to human health than any other common air pollutant. PM causes decreased lung function, increased respiratory symptoms, aggravated asthma, development of chronic bronchitis and premature death (Kim *et al*. 2014). Londahl *et al*. (2007) described the way particulate matter affects health; Figure. 3.5 shows a comparison of the size between $PM_{2.5}$ and PM_{10} against the average diameter of a human hair (~70 µm) and fine beach sand (~90 µm).

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Figure 3.5: Size Comparison of $PM_{2.5}$ and PM_{10} (Guaita *et al*. 2011)

Londahl *et al*. (2007) stated that particles can penetrate within the respiratory tract initially by entering the nasal passages and into the alveoli. Due to their excessive penetrability, they then enter deep into the lungs. These particles are then deposited within the tracheobronchial tree, respiratory bronchioles and the alveoli where gas exchange occurs (Figure 3.6). Eventually they enter the blood stream resulting in significant health problems.

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Figure 3.6: Deposition Potential for Particles of Varying Sizes (Londahl *et al*. 2007)

Figure 3.7 and Table 3.7 show the levels of PM_{10} in Bangalore over the years 2006-2013 at the 6 sites under consideration. All 6 areas have varying levels of PM_{10} with classifications as mainly High or Critical. Over the 8 years the overall increase in each location is:

- Yeshwanthpur 80.28%
- AMCO 161.21%
- Peenya 17.48%
- KHB 215.97%
- Graphite 76.47%
- Victoria 119.34%

Figure 3.7: PM_{10} Levels at 6 sites in Bangalore, 2006-2013 (KSPCB 2014)

In general, all 6 sites under consideration have exceeded the recommended PM_{10} level of 60µg/m^3 with all areas having an EF of over 2 (KHB having the highest EF of 3.03). Particulate matter has been identified to have direct adverse effects on morbidity and mortality rates. According to the WHO (2011a), multi-city studies demonstrated that increases in PM_{10} by 10µg/m^3, 50µg/m^3 and 100µg/m^3 resulted in increased mortality rates of 1%, 3-6% and 10-17%, respectively. If this mortality reflection is translated to Bangalore's levels of PM_{10}, then projected increases in mortality rates in Graphite and YPR would be 10-17%, 8% in the AMCO residential area and 6-9% in Peenya and Victoria.

Table 3.7: PM_{10} Levels, EF and Air Pollution Level Classification, 2006-2013

	YPR [RESIDENTIAL]			AMCO [RESIDENTIAL]			PEENYA [INDUSTRIAL]		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	71.0	1.18	**H**	64.7	1.08	**H**	103.0	1.72	**C**
2007	61.0	1.02	**H**	49.0	0.82	**M**	78.0	1.30	**H**
2008	67.0	1.12	**H**	71.0	1.18	**H**	101.0	1.68	**C**
2009	125.0	2.08	**C**	71.0	1.18	**H**	120.0	2.00	**C**
2010	221.0	3.68	**C**	65.0	1.08	**H**	74.0	1.23	**H**
2011	100.0	1.67	**C**	80.0	1.33	**H**	92.0	1.53	**C**
2012	107.0	1.78	**C**	58.0	0.97	**M**	89.0	1.48	**H**
2013	128.0	2.13	**C**	169.0	2.82	**C**	121.0	2.02	**C**
STANDARDS	**60**$\mu g/m^3$			**60**$\mu g/m^3$			**60**$\mu g/m^3$		
	KHB [INDUSTRIAL]			**GRAPHITE [INDUSTRIAL]**			**VICTORIA [SENSITIVE]**		
	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL	LEVELS ($\mu g/m^3$)	EF	POLLUTION LEVEL
2006	57.6	0.96	**M**	91.8	1.53	**C**	69.3	1.16	**H**
2007	63.0	1.05	**H**	194.0	3.23	**C**	80.0	1.33	**H**
2008	78.0	1.30	**H**	129.0	2.15	**C**	66.0	1.10	**H**
2009	69.0	1.15	**H**	184.0	3.06	**C**	63.0	1.05	**H**
2010	56.0	0.93	**M**	122.0	2.03	**C**	59.0	0.98	**M**
2011	72.0	1.20	**H**	122.0	2.03	**C**	64.0	1.07	**H**
2012	179.0	2.98	**C**	86.0	1.43	**H**	51.0	0.85	**M**
2013	182.0	3.03	**C**	162.0	2.70	**C**	152.0	2.53	**C**
STANDARDS	**60**$\mu g/m^3$			**60**$\mu g/m^3$			**60**$\mu g/m^3$		

3.11 Summary

This chapter has highlighted the fact that Bangalore is experiencing varying levels of pollution with certain areas having either High or Critical levels of the pollutants. Although levels of SO_2 remain under recommended standard, levels of NO_x vary in the city and levels of PM are high or critical in all areas. Exposure to elevated concentrations of fine PM can trigger health risks and can reduce life expectancy by several months to few years. The critical levels of PM are likely to have a damaging effect on the health of the citizens in Bangalore that may result in a tremendous burden on the public health system.

There are no studies or evidence to indicate safe levels of PM or a threshold below which there are no adverse effects on health. However, studies have demonstrated that average life expectancy has increased by reducing levels of air pollution through interventions and reductions in pollution. Since the burden of air pollution on health is significant, even at relatively low concentrations, the effective management of air quality is necessary to reduce the health risks to a minimum.

For informed decisions on the protection of the health of populations from elevated levels of air pollution, an understanding of spatiotemporal variance of air pollutant patterns is necessary. Tools such as Geographic Information Systems (GIS) have gained popularity in the air quality mapping and analysis and in public health applications.

The next chapter explores the background of GIS and its applications in health. The design and development of ENVHIS is discussed, which will facilitate Bangalore in the spatiotemporal analysis of air pollution and CVD and equip the stakeholders with an information system in order to take informed actions.

Chapter 4: Geographical Information Systems

4.1 Overview

The previous chapters discussed the issues with CVD health in Bangalore and also explored the air pollution scenario in the city. It was envisaged that a GIS based system would enable the spatiotemporal analysis of air pollution and CVD, by integrating the datasets and graphically representing the results, the system also operates as a decision-support tool.

This chapter begins with a discussion of the background of GIS, its applications in health and the benefits of using GIS. The sequential phases of the development of the ENVHIS application based on a GIS platform are explained with a brief summary of the system components. The design of the ENVHIS also includes exploring the datasets and defining the variables for the datasets.

4.2 Introduction

Geographical location is an important determinant for any activity. In the health data, there is a spatial component that can be tied to a place such as an address, postcode, region or coordinated reference location. To gain a better advantage of the spatial and temporal components in decision making, the appropriate tools must be employed.

Geographical Information Systems (GIS) are emerging as an important tool to assess the health needs of people, map incidence and prevalence of disease, locate risk factors, as well as in supporting the planning, management and modelling of healthcare systems to assess the delivery of care where necessary (Cromley 2003; McLafferty 2003). GIS is an integrated computer system that stores information about spatial and related non-spatial data (ESRI 2012).

Boulos (2004) describes GIS as a potentially powerful resource due to their ability to integrate separate sets of data from disparate sources, provide analysis to produce new information, provide mapping and visualisation techniques thus empowering decision makers in knowledge management and decision making. GIS is gaining popularity in environmental and demographic research areas and is increasingly used in health interventions for areas and populations at risk (Caley 2004).

4.2.1 GIS Applications in Health

Due to the strong capabilities of GIS they are used in a broad range of applications such as:

- Urban planning
- Forestry
- Climate science
- Military use
- Emergency management
- Epidemiology
- Public health

The concept of association of health and spatial location has been around since ancient times. One of the earliest examples to demonstrate that people began to realise that diseases in humans and animals are associated with location is for example, when Marco Polo became aware that hoof diseases in animals were caused by the local water supply in given areas (NRC (US) 2007). Another well-known earliest example of using maps to track disease was the discovery of the cause of cholera outbreak by Dr. John Snow (Shiode 2012). The physician used hand drawn maps to illustrate the locations of deaths in London. He then superimposed the maps with locations of water pumps and noticed an area where cholera deaths were clustered around a certain pump. When the handle of the pump was removed, deaths began to significantly decrease. This was a significant contribution to a field known as disease diffusion mapping.

Boulos *et al*. (2001) divide geographical studies on health activities into geography of diseases and geography of healthcare systems. The geography of disease relates to disease outbreaks such as detection, modelling, exploration of disease outbreaks, disease risk factor analysis and etiology hypothesis. The geography of healthcare systems records details and abilities about healthcare providers, supports health facility planning, management and delivery for balancing needs in healthcare access.

GIS is increasingly being used in public health applications. Public health studies the health of populations rather than individuals, and is believed to focus on prevention rather than treatment. By georeferencing health data, disease etiology can be better understood, any patterns can be determined and appropriate control and prevention actions taken. In addition, GIS can also be used in identifying disparities and inequalities in income, availability of quality healthcare and determining where new development could be focused (Briney n.d.).

4.2.2 GIS Applications in Environmental Health

GIS has been widely used in determining environmental exposures and effects on health. Some examples are Guthe *et al*. (1992) who used GIS to predict populations of children at high risk of exposure to lead in New Jersey. Wartenberg *et al*. (1993) identified populations at risk of exposure to magnetic fields. Glass *et al*. (1995) used GIS to investigate environmental risk factors for Lyme disease in Maryland, USA.

A study by Wang *et al*. (2011) focused on Air Quality data for Ozone and asthma hospitalisation rates between the years 2000-2008. The project linked different existing systems, such as environmental and disease tracking system, to assist both the environmental agencies and health professionals to identify geographical and geospatial patterns of populations at risk. The data was geocoded into a database and analysis functions such as overlay of layers were performed. Queries on the data on the basis of county, health outcome and year were displayed in maps, charts and tables. This system, according to Wang *et al.* (2011), has facilitated public health officials and environmentalists to increasingly use GIS technology for data presentation, analysis and in the role of decision making.

Health GIS is widely receiving attention and within the domains of environmental health, disease ecology and public health, GIS are becoming an indispensable tool for processing, analysing and visualising spatial data (Kistemann 2002).

4.3 ENVHIS System Components

This section provides an overview of the Environmental Health Information System (ENVHIS). The components of a Geographical Information System include a database, spatial information and an interface that links them together, the ENVHIS is described as including the following main functional modules (Figure 4.1):

- Data input module
- Data storage and retrieval module
- Data manipulation and analysis module
- Data output and display module

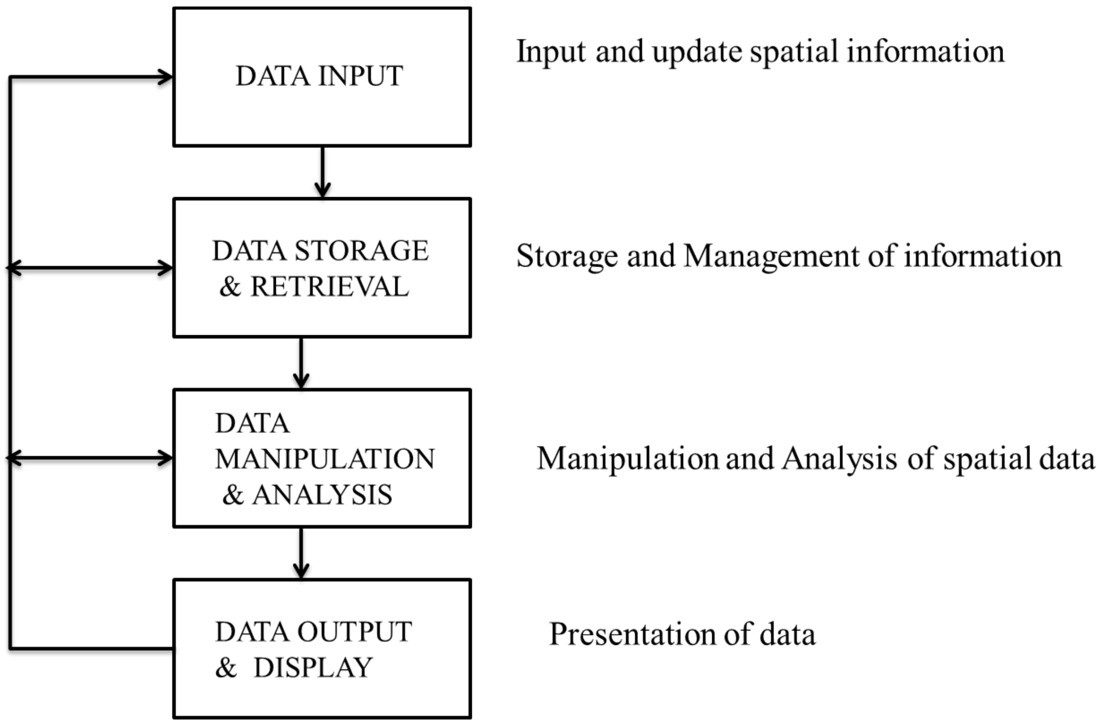

Figure 4.1: Components of GIS

4.3.1 Data Input Module

The main functionality of the data input component is to capture, collect and transform spatial and thematic data and, where necessary, convert it to a digital format to be stored. A map digitising system is used to convert existing paper maps into digital form (DeSavigny and Wijeyaratne 1995). The data entered into the ENVHIS can be described as spatial references and their attributes such that:

- Spatial reference data are the coordinates that provide the location of the information being inputted and are described either in terms of latitude and longitude or as columns and rows.
- Attributes are the defining features of these references and include the name, length, etc. of the geographic reference.

4.3.2 Data Storage and Retrieval Module

The function of the data storage and retrieval component is to structure and organise the spatial data according to their references and attributes within the ENVHIS that can be retrieved for spatial analysis. The subsystem organises the data, spatial and attribute, in a form which permits it to be quickly retrieved by the user for analysis, and permits rapid and accurate updates to be made to the database. This component usually involves use of a geodatabase for storing spatial data along with their associated attribute data. Spatial data is encoded and maintained in a proprietary file format. Spatial data describes the absolute and relative locations of geographic features and attribute data describes characteristics of the spatial features (ESRI 2012). The integrity of the spatial data is maintained and any business rules and relationships to the data are applied. The geodatabase supports all the different types of data:

- Geographic features
- Attribute data
- Coordinate data
- Demographic data
- Environmental data
- Health data

4.3.3 Data Manipulation and Analysis

The function of the Data Manipulation and Analysis subsystem is to provide the spatial analytical functionalities that derive information and result in a deeper understanding of the data. The component provides analytical tools such as buffer, queries, geocoding, network analysis that allow for the user to answer any query information or create visual maps. They also include other strong spatial analysis functions such as overlay, proximity analysis, geostatistical analysis, spatial statistics, raster analysis, etc. (Raju 2003).

GIS mapping technologies can generate maps for health in desktop or in Web applications. The mapping technologies can produce interactive interfaces for users, with the support of GIS basic functions such as zoom in, zoom out, pan and hyperlink. Gao (2010) differentiates two types of mapping technologies:

- Static Mapping
- Dynamic Mapping

Static mapping is a passive mapping process where the cartographic representation and mapping variables are usually pre-defined. Web mapping applications generally use static mapping wherein the maps already exist or are rendered. Organisations may maintain electronic library resources that provide maps in the form of publications, reports, etc. categorised by geographical area/topic (Gao 2010).

Dynamic mapping on the other hand is an active mapping process, in which the cartographic representation and map variables can be set by users interactively. Users can customise maps according to their need that may include changing colour schemes of the maps or mapping activities (Gao 2010).

4.3.4 Data Output Module

The data output subsystem effectively communicates the results from the analysis in the form of graphic displays that are either maps or charts and also in tabular reports. This subsystem conveys the results of analysis to the people who make decisions about resources. Maps and other graphics can be generated, allowing the viewer to visualise and thereby understand the results of analyses or simulations of potential events (ESRI 2012).

4.4 ENVHIS System Design

This section discusses the sequential steps involved in the development of the ENVHIS. The system design process includes the conceptual, logical and physical design phases and each phase results in the creation of a database model. Data modelling is a process that defines and analyses data requirements to represent and manipulate information within a database system (Levene 1992).

The conceptual model is described as human-oriented, often partially structured and the first level of abstraction from reality (Longley 2005). In the conceptual data modelling stage, the data requirements are analysed and modelled; this involves the design of a conceptual schema for the database (Lightstone *et al*. 2005). For the ENVHIS, the conceptual modelling defined the linking of the geometric and the thematic data and how this could be represented in the geodatabase. Thus, the conceptual modelling stage briefly described the data requirements, the relationships and data types.

The conceptual modelling is followed by the logical data model stage. This stage involves the description of the data in as much detail as possible. The steps of this stage include the definition of all entities and their relationships, the specification of attributes for every entity and also defining the primary and foreign keys (Lightstone *et al*. 2005). The different database structures are also considered at this stage, this includes object oriented database, relational database, hierarchical or network database structures (Stajano 1998). The relational database structure has been selected to form the logical data model design.

The next step consists of system implementation that involves the mapping of data into structures. The system components include GIS-specific software and applications, as well as database support, hardware, supporting systems software and systems integration. The main objective of the data modelling technique is to determine the logical structure of the ENVHIS and to populate the database that results in an overall information framework.

4.4.1 Conceptual Design

A conceptual model can be defined as an abstraction that only defines the logical concepts without revealing any details of implementation or of data storage. A conceptual model is the first step for classifying, identifying and representing the real world phenomena to the GIS system. As the conceptual model is only an abstraction, this cannot be directly represented in the system.

The primary requisite at this stage was to identify all the information requirements, such as the requirements of the system application, the types of features required, etc. Based on the requirements, an application schema was then defined. This comprises a set of features with each feature type consisting of a specification of the attributes, their operations and associations.

The conceptual model focussed on two different aspects of reality. Firstly, constructs were provided to represent spatial values that are referred to as the spatial data model. Secondly, the geographic application schema was provided that described the data schema that manipulates the geographic information. Thus, the conceptual model defined the application schema filled with feature instances that represent a real world phenomenon. Figure 4.2 represents the conceptual schema of the database.

The case study area, Bangalore, is considered as a spatial unit from which the various data sources are collected. The following assumptions have been set up to govern the ENVHIS:

- Bangalore has a base map;
- This base map has other categories of maps, such as road networks, rail networks, ward delimitations and zone delimitations;
- The study area has demographic categories;
- Demographic categories are defined by age, gender, year and ward;
- The city has air quality monitoring stations;
- AQM stations record various pollutants for years described at fixed and mobile monitoring stations;
- CVD data is recorded;
- CVD data includes gender, age, cause of death, date of death and place of death.

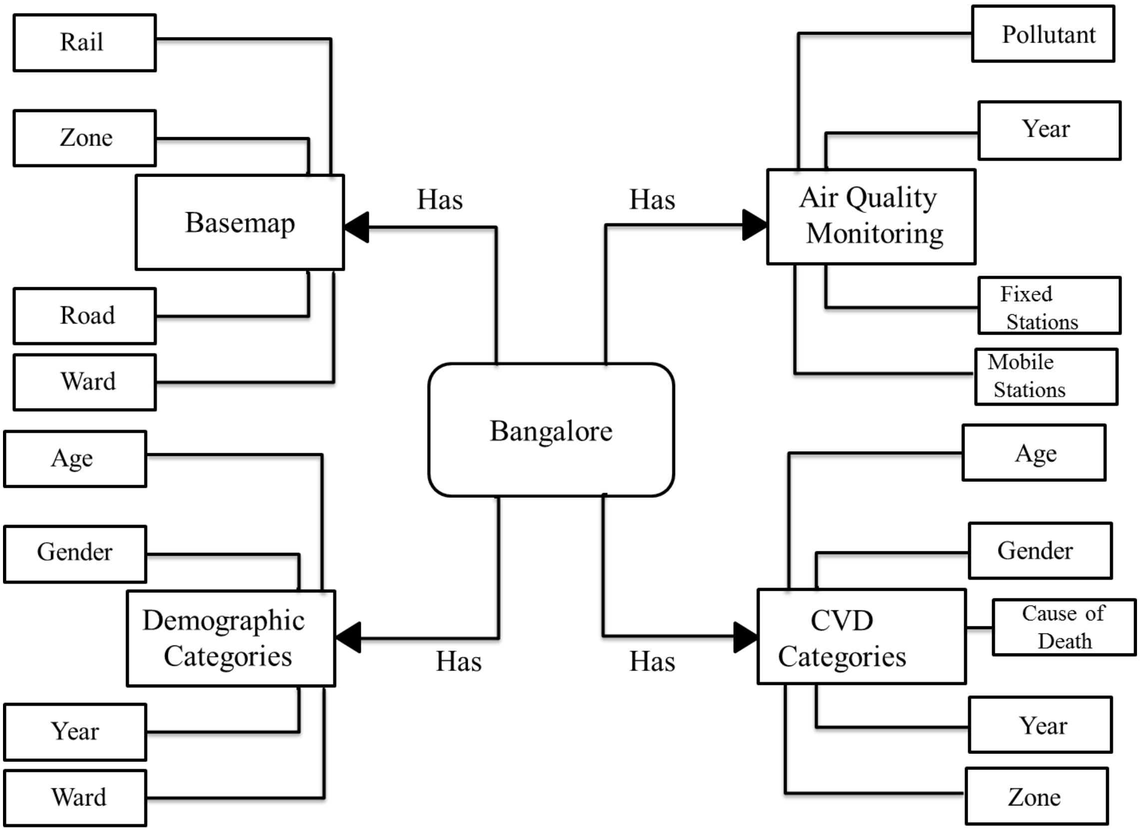

Figure 4.2: Conceptual Schema of Database

4.4.2 Logical Design

The logical modelling is the intermediate level of data representation and is the stage which represents the data flows, inputs and outputs of the system. The Entity Relationship (ER) diagrams are defined at the logical design phase that results in a set of relational schemas.

A good ER diagram is essential in the creation of a good database as the ER diagram can be directly translated into database tables in a relational database (Riccardi 2002). Each row of the database table represents an instance of that entity. An attribute of an entity is a particular property that describes the entity. A relationship is the association that describes the interaction between entities.

For the ENVHIS the steps in designing the ER diagram include:

- Identification and definition of entities: this relates to tables in the database;
- Defining the attributes: these are the columns in the database;
- Analysing the nature of relationships: the primary and foreign keys are assigned based on the relationships;
- Creating the ER Diagram: Relational implementation.

Once all the requirements were identified and defined, the ER diagram was created for the ENVHIS and is represented by the Figure 4.3.

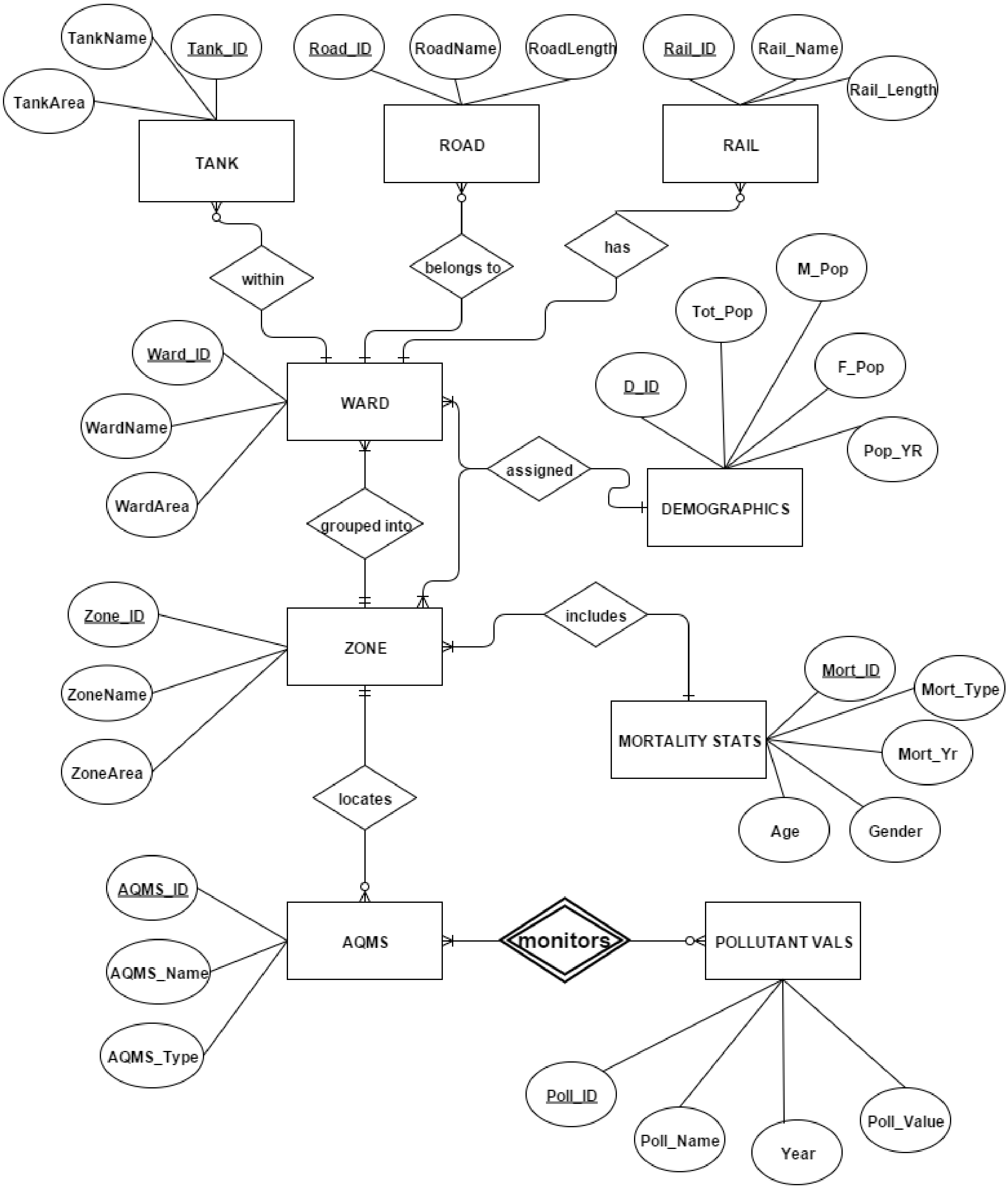

Figure 4.3: ER Modelling of ENVHIS

4.4.3 Physical Modelling

On describing the conceptual and logical modelling, the next step was to realise the system. This level dealt with system configuration such as hardware, software, file structures and access methods that constituted the implementation phase. The implementation phase included the vital geodatabase design, formatting spatial and non-spatial data, establishing compatibility and relationships between the various sets of data obtained.

4.4.4 The Software

ArcGIS is a geographic information system designed for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analysing mapped information, sharing, discovering and managing geographic information in a database. The system provides an infrastructure for creating maps and geographic information available throughout an organisation, across a community, and openly on the Web (ESRI 2012).
There are other open-source GIS systems available such as MapInfo and Quantum GIS. The main factors that determine the selection of software are cost, training, system capacity, speed, scalability and technical support from the system provider. The financial stability and market position of a provider also plays a factor in the choice of a system. On investigation, the open source GIS and ArcGIS exhibit similar functionalities, however ArcGIS was selected due to a combination of several factors. It has powerful spatial analysis capabilities and the added benefit of an embedded database system. It is also one of the most easily available and widely used commercial GIS packages.

Furthermore, ArcGIS supports an effective three-tier architecture and is advantageous for the integration of data and the manipulation of other layers that all result in valuable information. ArcGIS also supports open standards that enable productive collection and modification of data and speedy implementation of geodatabases.

In addition, ArcGIS provides an opportunity to readily use software upgrades and other improvements in technology. There is also extensive documentation and support for ArcGIS provided by Environmental Systems Research Institute (ESRI) who are international suppliers of GIS, Web GIS and geodatabase management applications (ESRI 2012).

4.4.5 Geodatabase

To map the structures from the previous logical design into the final physical design, a new geodatabase was created. A geodatabase is defined as the top-level unit of geographic data. It includes datasets, feature classes, object classes and relationship classes. The ability to store geographic data, perform spatial analysis on the data and present the result in map form, aside from the customary table and text forms, is what distinguishes a geographic database from other databases (ESRI 2012).

The new geodatabase was created using ArcCatalog which is an application that provides a catalog window used to organise and manage various types of geographic information for ArcGIS Desktop. The types of information that can be organised and managed in ArcCatalog include:

- Geodatabases
- Raster files
- Map documents, globe documents, 3D scene documents and layer files
- Geoprocessing toolboxes, models and Python scripts
- GIS services published using ArcGIS Server
- Standards-based metadata for the GIS information items
- And much more

ArcCatalog organises these contents into a tree view that can be organised with the GIS datasets and ArcGIS documents; information can then be searched and managed efficiently (Figure 4.4).

Figure 4.4: ArcCatalog in the ENVHIS

4.4.6 Feature Class

Once the geodatabase was created, the feature classes were described and grouped into classes that have common characteristics. Feature classes are homogeneous collections of common features, each having the same spatial representation. Points, lines and polygons are the most commonly used feature classes, and examples from the Bangalore data include:

- Points – Features that include point locations (with latitude and longitude as x,y attributes) (Figure 4.5). Example of point features for Bangalore includes the air quality monitoring stations.
- Lines – Represent geographic objects such as roads, streets, rail networks that have length but not area (Figure 4.6) Example of line features for Bangalore include the road and railway networks.

* Polygons – These are features that represent the shape and location of homogeneous feature types; land-use, for Bangalore the wards and zones are represented as polygons that have shape, location and area (Figure 4.7)

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Figure 4.5: Point Feature class – Air Quality Monitoring Stations

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Figure 4.6: Line Feature class – Road Networks in Bangalore

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Figure 4.7: Polygon Feature class – Zones in Bangalore

4.4.7 Tables

Tables represent one of the three key dataset types in GIS, along with feature classes and image datasets (referred to more generally as raster datasets in ArcGIS). GIS users employ tables to store descriptive attributes. Tables are also the mechanism that is used to store feature classes and raster datasets in each geodatabase.

In ArcGIS, a table has a series of rows and columns used to store descriptive information (Figure 4.8). Each row has a series of fields with values. The same fields (or columns) appear in each row. Each column has an associated type, such as an integer number, a real number with decimal places, a text field, a date field, a shape field or similar binary field in order to include more sophisticated structures such as feature geometry or imagery.

Each row in a table can be considered as an object, and the fields hold the descriptive properties of each object. In the case of feature classes, the object in each row is a feature and the shape column holds the feature's geometry (such as a point, line, or polygon). In the case of a nonspatial table (in other words, a typical attribute table), these are sometimes referred to as "aspatial" or nonspatial objects.

Figure 4.8: Table – PM_{10} Values for Years 2010-2013

4.4.8 Relationship Class

Relationships between features or objects are stored in a table in the geodatabase and this is referred to as the relationship class. The relationship class is used to model any dependency between objects. Relationships manage associations between the objects in tables. Creating relationship classes between tables in a geodatabase can help maintain referential integrity, efficiently edit related tables, and provide the ability to query related tables. The following types of relationships between tables in a geodatabase are supported:

- Spatial relationship - Relates feature to feature
- Non-spatial relationship - Relates row to row
- Spatial to non-spatial relationship - Relates feature to row

4.4.9 Feature Dataset

All the feature classes and relationship classes that share a common spatial reference are grouped together. This collection is defined as the feature dataset. Feature datasets are formulated to allow the participation of the objects that are grouped together for specific functionalities. The characteristics that determine the grouping of feature classes are:

- Same coordinate system.
- Participation in topology.
- Participation in relationship class.
- Participation in geometric network, network dataset, schematic dataset, parcel fabric, or terrain dataset.
- Associated feature-linked annotation.

On completion of the system as described that includes the feature classes, tables, relationship classes, feature datasets, the next step is to input the data into the system.

4.4.10 Data Collection

Data collection is the procedure during which intended datasets are collected according to the geospatial data-related standards or user designed rules. The datasets include any primary or secondary data accompanied by metadata or other required documents. In the case of Bangalore, the data are obtained from governmental sources. The data sources are mainly secondary sources, meaning that there is no control over data collection, the quality of the data or the variables collected.

4.4.11 Secondary Data

The data for this research is mainly from secondary sources in Bangalore. This study is aimed at the whole population rather than a section or sample, hence the choice of using secondary sources of data was deemed fit. Secondary sources help define the entire population and are essential to represent it and draw conclusions. Secondary data is cheaper to collect than to design a process of collecting primary data, and more information can be extracted through secondary data than through a process of primary data collection. The time taken in collecting the secondary data is considerably lower than for the primary data collection. The assembly and analysis of the secondary data also determines the alternative course of action necessary that might be pursued in future work (Andersen *et al.* 2011).

The following questions determined the choice of using secondary data:

- Does the data help address the specified research questions?
- Does the data apply to the population of interest?
- Does the data cover the time period of interest?
- Are the definitions, data collection methods and systems of measurement acceptable?
- If not, can the data be revised?
- Is the risk of bias high?
- Can the data be verified?

4.5 Datasets

The datasets obtained for this research were:

- Spatial Data
- Demographic Data
- CVD Mortality Data
- Air Pollution Data

4.5.1 Spatial Data

The base maps (major roads, water bodies and railway lines) are digitised using 1:50,000 topographic sheets obtained from Survey of India. Survey of India is a National Survey and Mapping Organisation responsible for mapping the country's domain and providing base maps (Survey of India 2012). The ward maps were obtained from BBMP in the .jpg format and later converted to .dwg format and finally to .shp format (UTM Projection).

The coordinates of the air quality monitoring stations are captured using a Garmin hand-held GPS and plotted onto the map with the same projection (UTM) system. The thematic maps consisting of base maps, ward delimiters, zone delimiters, highways and major road networks, water bodies and rail network are entered into ENVHIS as .shp files consisting of wards and zones as polygons; roads and rail networks as lines; air monitoring stations as points. The attributes for these mainly include the name, area, length, latitude, longitude, etc.

4.5.2 Demographic Data

A census is the procedure where information about a country's population and its characteristics are systematically acquired and recorded. The UN (2010) also recommends that the census of a country is carried out every 10 years. The latest census in India was carried out in 2011, this being the 15th national census survey conducted by the Census Organisation of India. This census was conducted in 2 phases, phase one included house listing and phase two was for the population. The country consists of a considerable number of villages, cities and districts that are grouped into 28 states and 7 Union territories (Census of India 2011). The national census covered all the areas.

Furthermore, the 2011 census included a number of parameters such as growth rate in population, rate of literacy, density of population, sex ratio and child sex ratio (0-6 years). In Bangalore, the BBMP is responsible and is the administrative body responsible for the civic and infrastructural assets of the Bangalore metropolitan area. The population data was obtained from BBMP for the 2001 census and the 2011 census. The variables that were obtained were:

- Name of the ward
- Ward number
- Zone
- Total Population
- Male Population
- Female Population
- 0-6 year old Total Population
- 0-6 year old Male Population
- 0-6 year old Female Population
- Literates – Total
- Literates – Male
- Literates – Female

4.5.3 Air Pollution Data

Air Pollution Data has been acquired from the KSPCB. The data for the years 2006-2013 have been obtained from the KSPCB as annual averages. The pollutants for which the data are consistently available are SO_2, NO_x and RSPM/PM_{10}. The annual average values for these pollutants for all 8 years were obtained for the 6 fixed locations in Bangalore:

- Graphite India Limited, Whitefield Road
- KHB Industrial Area, Yelahanka
- Peenya Industrial area, Regional Office Peenya
- Victoria Hospital, Chamrajpet
- AMCO batteries, Mysore Road
- Yeshwanthpur Police Station

Any values provided for mobile monitoring locations were not considered since obtaining a trend or association with intermittent values is not possible. The locations of the monitoring stations are entered as shape files and the values corresponding to each monitoring station are entered into an attribute file according to the years obtained. The variables used are as represented in Table 4.1.

Table 4.1: Variables for AQM

Variables	Details
AQM Station	Graphite
	KHB
	Victoria
	Peenya
	YPR
	AMCO
AQM Station Type	Industrial
	Residential
	Sensitive
Year	2010- 2013

Pollutant Name	SO_2
	NO_x
	PM_{10}

4.5.4 CVD Data

The data register containing individual data are entered into a central database by the BBMP and the death registers are sent to the Department of Economics and Statistics (DES) which maintains a database used for statistical reporting. The CVD mortality data was obtained from the BBMP based on central repository data register that contains the mortality data integrated from all the registration centres in Bangalore. A total of 1,090,899 historic records were obtained for the years 1930-2013. Data was recorded according to year of death, zone, age, gender and cause of death. The details of the zone names and age groups are represented in Table 4.2. Data management tools (Excel and Access) were used for the management of the data prior to entering it into the ENVHIS.

Table 4.2: Variables for CVD

Variables	Details
Zone	East
	West
	South
	Mahadevapura
	RR Nagar
	Dasarahalli
	Mahadevapura
	Yelahanka
	Bommanahalli
Age Groups	0-5
	5-14
	15-24
	25-34

	35-44
	45-54
	55-64
	65-74
	75+

The cause of death is coded according to the WHO's ICD-10 classification for diseases. Codes start from A00-Z99, with CVD mortality codes ranging between I00-I99.

4.5.5 Relevant Data and Challenges

One of the significant challenges in using GIS is obtaining the relevant data for the system. Data lies at the heart of GIS and is defined as an abstraction of reality and it is crucial to decide the data that is required for the purpose. The relevant data must also be in accordance with the capabilities of the GIS. The quality of the data is very important and must adhere to data quality aspects such as accuracy, precision, time, currency and completeness. Aronoff (1989) stated that there is an inverse relationship between data quality and data cost.

Although the benefits of GIS have been highlighted and its applications have been demonstrated in developed countries, the use of GIS is limited in developing countries due to diverse challenges (Ramasubramanian 1999). These may be lack of infrastructure, lack of skilled human resources, lack of knowledge and awareness and the relatively large costs associated with its setup. GIS is a fairly expensive technology for most developing nations as there are costs towards data collection, cost of software and hardware, and costs of employing and training GIS staff. Some countries also lack reliable internet connections or have the disadvantage of limited speed connections that make communication and data transfer difficult. Shortage of skilled staff, costs of training and lack of funding are perceived as the biggest constraints (Stuart *et al*. 2009). The factors that inhibit implementation of GIS in developing countries are listed in Table 4.3.

In India, however, a National Spatial Data Infrastructure began in the early 2000s when the country recognised the true power of GIS. The country has a wide disparity in all divisions, be it economical, social or cultural. It is this complex nature of the country that demanded a system that can easily map, note changes to and understand the complexity of societal and economical diversities and growth. The government's vision is to reduce the disparity and expedite development that is beneficial to the society, especially the most disadvantaged (ArcNews, 2013).

This vision led to setting up of the first geoportal in India – Karnataka's geoportal. The state is a pioneer to set up the prototype which will be a model for the national geo-portal. Karnataka's geoportal is an Internet based Geo Spatial Data Directory that allows the users of the system to share information related to political and administrative boundaries. Users can also explore the geography of the state, the demographics of any area, resources related to agriculture or infrastructure facilities.

The Portal states that it will be essentially used for the following objectives (Karnataka Geo-Portal 2012):

- Bringing together geo spatial knowledge and information under a common platform, which till date has existed as a disparate system and unknown to quite a wider section of the society, institutions, scientific community and government departments
- Gateway for various data generating agencies to share the information across various government departments, NGOs, academies, industries and scientific organisations
- Provide spatial data dictionary and map directory for the state
- Analyse the needs of various government programmes
- Facilitate decision support system and help in local level planning
- Eventually can be used for the data sale and purchase, which can be part of the state revenue generation

The vision report however states that in spite of the wide usage of GIS as a technology, the potential of GIS has not yet been fully exploited for decision support by planners, stakeholders, decision makers, citizens, and others. Although some of the initiatives have been successful and have proved the potential of GIS, it has yet to achieve a full-service orientation and become a core component of the process of governance, planning, and nation building.

Exploration of this geo-portal and the projects revealed that the focus on the effects of poor air quality on health has not been considered (Karnataka Geo-Portal 2015).

Table 4.3: Factors found to have inhibited efforts to implement GIS (Stuart *et al*. 2009)

4.6 Summary

The environment plays a vital role in determining the health of humans, thus where a person lives can be a major determinant of their health and well-being. This chapter has discussed the development of the ENVHIS application and its ability to input, store, analyse and present information that will support decision-making. The relevant datasets in the right format are important for this system; the next chapter will discuss the data quality of the datasets obtained and also investigate any limitations.

Chapter 5: Data Quality

5.1 Overview

Data management can be described as the process of controlling the information generated during the research study process. Any research will require some level of data management and forms the integral part of the research process. The data management is considered to be particularly challenging and how the data is to be managed depends on the types of data involved, how it is collected and stored, and how it is to be used - throughout the research lifecycle.

The acquired data have to be processed by detecting and correcting inaccurate records. The term data cleansing used mainly in databases refers to identifying incomplete, incorrect, inaccurate, irrelevant parts of the data and then replacing, modifying or deleting this dirty data or coarse data (Hellerstein 2008).

The actual process of data cleansing may involve removing typographical errors or validating and correcting values against a list of entities such as rejecting any address that does not have a valid postal code or correcting records that partially match existing, known records. Data cleansing may also involve activities like harmonisation of data and standardisation of data.

This chapter discusses the data management of the demographic, pollution and CVD and mortality data. The data obtained from the stakeholders are managed and cleaned up according to the variables defined. Any limitations in the dataset are addressed and a framework for data improvement is proposed.

5.1.1 Demographic Data

Demographics, the statistical characteristics of the human population, are used for many purposes including analysis of population characteristics, distribution and for planning purposes. Government entities, for example, use demographics to analyse trends in population and housing data in order to plan for city services and programmes to benefit residents and businesses. A complete demographic analysis involves the quantification of data, analysing trends of that data, identifying particular needs, and then making projections. This information can then be used to pinpoint the needs of certain populations and make projections and decisions based on those needs.

The Bangalore Municipal Corporation known as Bruhat Bangalore Mahanagara Palike (BBMP) is the administrative body responsible for the civic and infrastructural assets of Bangalore city. BBMP is run by a city council comprising of elected representatives, called ‘corporators’ for each ward of the city. For ease of administration, the 198 wards are grouped into 8 different zones, each with a Joint Commissioner who works directly under the BBMP Commissioner. The demographic data contained herein has been gathered from BBMP.

5.1.2 Population in 2001

Data for the census of 2001 has been obtained from the BBMP for the 198 wards in Bangalore (Table 5.1). The variables include total population, male and female population. The census data for 2011 for the same variables has also been obtained from BBMP (Table 5.2).

Table 5.1: Population Statistics in 2001 (BBMP 2014)

5.1.3 Population in 2011

The population in Bangalore in 2001 was 5,840,155 of whom 3,059,580 were males and 2,780,575 females. By 2011 the population rose to 8,370,161 with 4,361,730 males and 4,007,755 females. This was an increase of about 2.5 million people in just 10 years contributing to 30.23% growth in overall population. The male population contributed to 52.39% of the total population in 2001 and female population 47.61%.

The ward population in 2001 ranged from 19,287 to 36,852, with Begur having the lowest ward population and Cottonpet with the highest population. By 2011, although Cottonpet only had a 1.68% increase in the population with a total of 37,207, in comparison Begur witnessed a 76.71% increase in population from 19,287 to 82,813, the highest percentage increase of all the wards. The percentage increase in populations in the 198 wards ranged from -43.34% to 76.71%. Approximately 30 wards saw a percentage decrease in population ranging from -43.34% to -1.62%. This decrease in ward population is mainly attributed to the commercialisation of the corresponding areas. Many areas, due to their high business concentration, are being converted from residential homes to business offices, and this may have contributed to a diminishing inhabitant population count. In 2001 the smallest ward population was 19,287 and the largest was 36,582, with a range of 17,295. By 2011 however, the smallest ward population was 21,120, but the highest was 93,830 with a range of 72,710.

Table 5.2: Population Statistics in 2011 (BBMP 2014)

5.1.4 Zone Statistics

The 198 wards in Bangalore are divided into 8 zones and this section discusses the zonal statistics for the population. Table 5.3 illustrates the population statistics for the 8 zones in 2001 and 2011 and also provides the gender distribution of the population.

Table 5.3: Zone Population Statistics 2001 and 2011 (BBMP 2014)

At zonal level, all zones witnessed an increase in population ranging from 10.02% to 61.25%. Figure 5.1 and Table 5.4 indicate that the zone population has witnessed explosive growth since the 2001 census. Zone Bommanahalli has the highest increase in population, at 61.25%, followed by RR Nagar with an increase of 55.07%. Dasarahalli, Bytarayanapura and Mahadevapura followed with the highest population increases of 53%, 51% and 46%, respectively. The inner zones of the city on the other hand had lower population increases with the East, South and West having a 14.3%, 19.23% and 10.225% increase, respectively. The South zone of the city is the most densely populated with a population of 2.012 million.

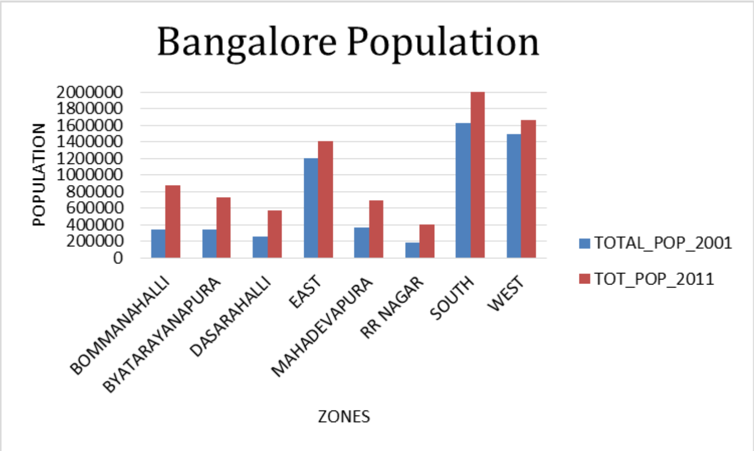

Figure 5.1: Zone Population Statistics 2001 and 2011

Table 5.4: Zone Population Increase (BBMP 2014)

5.1.5 Graphical Representation of Demographics using GIS

This census data was entered into the ENVHIS in the feature class created for the ward and zone features. The demographic maps were produced using Choropleth maps. Choropleth maps use fill colour in polygons for coding. It is a thematic map in which areas are distinctly coloured or shaded to represent classed values of a particular phenomenon. Using the Choropleth maps, the areas in Bangalore are shaded in proportion to the population measurement of 2001 and 2011 and displayed on the map (Figure 5.2).

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Figure 5.2: Bangalore Population – 2001 and 2011

It is visually more evident from the Figure 5.2 (also refer to Appendix 1) that the outer areas have grown larger in population than the inner wards. Central Bangalore i.e., West, East and

South zones were the original areas of Bangalore, with the outer areas being gradually added to the city to accommodate the growing population.

5.1.6 Data Quality

Census data is vital for a country's policy making, forecasting, economic performance, etc. Data also have to conform to the dimensions of data quality (Turner 2002). The dimensions for data quality for the census data of Bangalore are assessed and illustrated in Table 5.5.

Table 5.5: Dimensions of Census Data Quality

FACTORS	DESCRIPTION
Amount of data	Sufficiency/Insufficiency of information
Timeliness	The Census of India conducts census on a regular basis. The WHO states that there has to be a minimum period for population count of at least every 10 years. The census in India is carried out every 10 years, there are certain countries which carry out the population count every 5 years e.g. Australia.
Objectivity	Whether the information was objectively collected
Relevance	The Indian Census of population is the official count of population and households and collects information on age, gender and other characteristics of the population.
Completeness	The expectation that certain attributes are expected to have assigned values in a dataset
Accuracy	The Census is carried out door-to-door and the census enumerators are well trained in the data collection. To achieve accuracy in data collection, a great deal of effort has been put into Census form design, collection procedures and processing.
Coherence	It is important for Census data to be comparable and compatible with previous censuses and other data produced by other bodies. Hence it is important to use standard classifications where available and appropriate to provide data comparability when needed.
Interpretability	Reference guides need to be provided with details of classifications and a glossary of definitions used to assist users to understand and interpret the data.
Accessibility	Data has to be accessible for any user.
Access security	Whether the information is protected against unauthorised access

5.1.7 Demographic Data Summary

With respect to the data quality factors as explained above, Bangalore (and India) have a robust system for census data collection and have been accurately producing census data reports that are relevant, timely, accurate and accessible. The parameters recorded and stored also play a vital role in the analyses of the data and their interpretations. The only issue that was highlighted with the census data of Bangalore was that data was unavailable for age breakdown; hence age specific crude death rates cannot be calculated.

Crude Death Rate (CDR) is the number of deaths in an area per 1000 population counted at midyear i.e.:

$$CDR = \frac{\text{Number of Deaths in Year}}{\text{Mid} - \text{Year Population}} * 1000$$

CDR ranged from a low of 1 per 1000 in United Arab Emirates to a high of 29 per 1000 population in Swaziland in year 2004. However, it has to be noted that CDR disregards the age structure of the population. Thus a CDR of 7 per population in 2010 in Sweden does not imply that the health status is nearly the same as in India as India's CDR was 7 per 1000 population in 2010. This is because India whose population is relatively young had only 8% of the population of age 60 years or more while Sweden had 23% (Indrayan 2012).

This is the reason that a country requires age-specific death rates. By adjusting for age differentials, the rates are brought to a common base and thus made comparable. Such rates provide an adequate comparison of the health status in two areas or at two times for that particular age group (Indrayan 2012).

5.2 Graphical Representation of Air Pollution using GIS

In Chapter 3, the levels of pollutants were obtained from 6 fixed monitoring locations in the city and the trends of the pollutants were discussed. The 6 fixed air pollution monitoring stations are plotted onto the GIS map illustrated in Figure 5.3 (also refer to Appendix 1). Three of these stations lie within the West region. One of the stations is in the Mahadevapura

Zone, one in Dasarahalli zone and the other in Bytarayanapura zone. Zones South, East, Bommanahalli and RR Nagar have no fixed monitoring stations.

Most studies obtain recorded pollution levels from the monitoring stations and average them for the whole city. But the nature of pollution especially particulate matter is such that they are spatially variable, based on various factors, such as size of particle, wind, location of structures and other meteorological conditions. Besides, this study proposes the use of a spatiotemporal methodology to determine any clusters or hotspots, this requires a coverage of the levels of pollutants for the entire surface of the city.

Figure 5.3: Fixed AQMS Bangalore

Maantay (2007) suggests that the effects of particulate matter should be examined in a ½ mile radius buffer. Averaging the particulate matter values over the entire city, based on just 6 monitors, will not provide a representative picture of the local pollution conditions.

Buffering can be described as the creation of a zone of a specified width around a point, a line or a polygon. It is also commonly referred to as the 'zone of specifed distance' around a coverage feature. These zones, or buffers, are often used in queries to determine which entities occur either within or outside the defined buffer zone (ESRI 2013). Buffering point data is the simplest form of buffering that involves the creation of a circular polygon about each point of radius equal to the buffer distance. Applying the ½ mile (800 m) radius buffer, the coverage of the monitoring stations for Bangalore has been generated as shown in Figure 5.4 (also refer Appendix 1). It is evident from the map that the stations still do not provide coverage for the entire city. Hence, to obtain the values at unrecorded locations in the city, there is a need to employ spatial interpolation methods to predict the pollution levels at unmonitored locations.

Figure 5.4: Buffer for AQMS

5.2.1 Spatial Interpolation Methods

Many air pollution studies (Zhang *et al*. 2013; Matejícek *et al*. 2006; Son *et al*. 2010) have considered spatial interpolation methods to produce maps of air pollution concentrations. Interpolation is necessary when the data does not completely cover the domain of interest in order to predict the values of attributes at unsampled sites, by using the known measurements made at locations within the same area. The Tobler's first law of geography states the justification underlying the assumption for spatial interplation i.e. points closer together in space are more likely to have similar values than points more distant (EPA 2004).

The interpolation techniques based primarily on distance are Inverse Distance Weighting and Kriging. Knowledge about the data that are to be interpolated is critical to selecting an appropriate interpolation method and to understanding the results produced by the interpolation. Characteristics of the data that are important to consider include spatial representativeness, temporal sampling frequency, measurement accuracy, and existence of spatial relationships or behaviours at varying scales (EPA 2004).

Kriging is a stochastic method of interpolation that incorporates the idea of randomness into the interpolation process. It assigns weights based not only on the distance between surrounding points but also on the spatial autocorrelation among the measured points, which is determined by modelling the variability between points as a function of separation distance. Kriging is problematic to use as when there are a limited number of spatial observations it can smooth the spatial pattern of pollution levels by not capturing the spatial complexity of the pollutant (Tecer and Tagil 2013).

Inverse Distance Weighted (IDW) interpolation is a deterministic method of interplation and does not incorporate statistical probability theory into development of the predictions. IDW uses a weigthed avearge of nearby points with distance being the only factor influencing calculation of the weight. IDW is computed as a function of the distance between observed sample sites and the site at which the prediction has to be made.

The formula (Deligiorgi *et al*. 2010) in which IDW method is based is the following:

$$z_{estj} = \sum [z_i / (h_{ij} + s)^p] / \sum [1 / (h_{ij} + s)^p]$$

Where z_{estj} : is the estimated value in point j

z_i: the observed value in point i

h_{ij}: the distance between points j and i

s: the smoothing factor, which decreases the probability that some point will have excessive influence in the estimated value and

p: the weighting factor which normally takes values from 1 to 5.

There are a few areas of concern with the IDW and other non-statistical averaging methods. First, the range of the interpolated values is constrained by the range of the measured values, i.e., no interpolated values will fall outside the observed data range. This means that any high or low points of the area under consideration will be lost if they are not sampled. Also, because of the nature of the averaging formula, areas outside of the sampled area will flatten to the mean value (EPA 2004).

There is no minimal sample size recommended in ArcGIS Spatial Interpolation IDW method. The interpolation method is dependent solely on the method used and the number of points available, 6 points were used in this research as data from only 6 fixed locations were available. A cross-validation exercise was used in this study to calculate the error difference in values. In this exercise, each measured point was removed and compared to the predicted value for that location. The error of the prediction surface was highlighted and discussed. Further research where data from more points are obtained will enable acquiring more accurate interpolation results. The impetus is that more the number of data points, more accurate the results of the interpolation.

The values obtained from the 6 stations for the pollutants SO_2, NO_x and PM_{10} for years 2006-2013 were input into the ENVHIS. The IDW analysis was applied to every pollutant for every corresponding year and the maps obtained.

5.2.2 Interpolated Maps of SO_2

The analysis of SO_2 in Chapter 3 revealed that the range of SO_2 in Bangalore over 2006-2013 was 12.4µg/m^3 recorded in 2012 in YPR and the highest was 21.7µg/m^3 in 2006, also recorded in YPR. The values for 2006-2013 at the individual point locations were inputted into the ENVHIS. The SO_2 levels are well below the recommended guidelines. The Figures

5.5-5.12 represent the interpolated maps. From the maps and the analysis discussed in chapter 3, it can be discerned that SO_2 levels are below the recommended standards that is 30µg/m^3 in Bangalore. The lightest green shade in the maps depicts the lowest levels of SO_2 and the darkest green shade has the highest levels.

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Figure 5.5: 2006 SO_2 Levels

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Figure 5.6: 2007 SO_2 Levels

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Figure 5.7: 2008 SO_2 Levels

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Figure 5.8: 2009 SO_2 Levels

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Figure 5.9: 2010 SO_2 Levels

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Figure 5.10: 2011 SO_2 Levels

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Figure 5.11: 2012 SO_2 Levels

Figure 5.12: 2013 SO_2 Levels

5.2.3 Interpolated Maps of NO_x

The NO_x levels ranged between 27.2µg/m^3 recorded in Victoria in 2011 and the highest value of 50.7µg/m^3 recorded at Graphite in 2006. While some places recorded levels above 40µg/m^3 and hence had an air pollution level of High, no area had critical levels of NO_x. Figures 5.13– 5.20 represent the interpolated maps of NO_x levels for the years 2006-2013. From the Table and maps it can be discerned that NO_x levels are normally below the recommended standards in Bangalore. The lightest shade of green in the maps depict the lowest levels of NO_x and the darkest green shade has the highest levels.

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Figure 5.13: 2006 NO_x Levels

Figure 5.14: 2007 NO_x Levels

Figure 5.15: 2008 NO_x Levels

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Figure 5.16: 2009 NO_x Levels Figure 5.17: 2010 NO_x Levels Figure 5.18: 2011 NO_x Levels

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Figure 5.19: 2012 NO_x Levels Figure 5.20: 2013 NO_x Levels

5.2.4 Interpolated Maps of PM_{10}

Figures 5.21-5.28 represent the maps of PM_{10} levels for the years 2006-2013. PM_{10} has a wider range of variability in the city. The darkest red areas have the highest levels of pollution. The standard for the annual average of PM_{10} set by CPCB is 60µg/m^3, which is already 3 times over the limit of 20µg/m^3 set by the WHO. Of the 6 years, only the years

2006, 2007 and 2010 recorded levels below the recommended standard of 60µg/m^3 in a few areas.

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Figure 5.21: 2006 PM_{10} Levels Figure 5.22 : 2007 PM_{10} Levels Figure 5.23: 2008 PM_{10} Levels

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Figure 5.24: 2009 PM_{10} Levels Figure 5.25: 2010 PM_{10} Levels Figure 5.26: 2011 PM_{10} Levels

Figure 5.27: 2012 PM_{10} Levels

Figure 5.28: 2013 PM_{10} Levels

Figures 5.29-5.31 highlight the areas with levels above the recommended standard. In 2006, only 3 wards (out of a total 198) had levels below 60µg/m^3; 2010 also had only 3 wards below the recommended level. Only 2007 had the highest number of wards - 18 wards with levels below the recommended standard. All the wards over the years 2008, 2009, 2011 and 2013 had levels above the recommended standard.

Figure 5.29: Years 2006, 2007, 2010 with PM_{10} levels below 60µg/m^3 in certain wards

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Figure 5.30: Years 2008, 2009, 2011 with PM_{10} levels below 60µg/m^3 in certain wards

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Figure 5.31: Years 2012, 2013 with PM_{10} levels above 60µg/m^3

5.2.5 PM_{10} Hotspots

Having assessed that most areas are affected by high levels of PM_{10}, further queries were performed to determine the hotspots in the city. Figures 5.32-5.39 provide the analysis and maps of the hotspots. It can be seen from the maps that, although the hotspots vary slightly over the 6 years, the Eastern zone of the city, in particular Mahadevapura consistently had the highest levels of pollution over all the years under consideration. Further research in this zone to assess its characteristics, such as vehicle mobility, traffic density, point sources of pollution, wind direction, etc, will help in understanding the cause for the high levels.

The areas in the West had higher levels of PM_{10} over the years 2006, 2010 and 2011. It has to be noted however that the zones South, RR Nagar and Bommanahalli do not have a single monitoring station. Care must be taken while identifying highly affected areas using interpolation as it is necessary to understand the uncertainty of these predictions. Further analysis and monitoring in these areas will definitely increase the understanding of the characteristics and the distribution of PM_{10}.

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Figure 5.32: 2006 PM_{10} Hotspots Figure 5.33: 2007 PM_{10} Hotspots Figure 5.34: 2008 PM_{10} Hotspots

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Figure 5.35: 2009 PM_{10} Hotspots Figure 5.36: 2010 PM_{10} Hotspots Figure 5.37: 2011 PM_{10} Hotspots

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Fig. 5.38: 2012 PM_{10} Hotspots

Fig. 5.39: 2013 PM_{10} Hotspots

5.2.6 Performance Testing using Cross-Validation

The performance of the interpolation scheme was tested using cross-validation, here one data point is withheld and the rest of the points are used to predict the values. The data is then measured and checked for the predicted and observed value at the missing location. Each station (Figure 5.40) was removed one at a time, interpolation carried out and values of SO_2, NO_x and PM_{10} measured, for the year 2010. Selected point locations at centres of zones RR Nagar, South, Bommanahalli and East were also measured, as these locations do not have a station, the variability was assessed with the interpolation.

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Figure 5.40: Air Quality Monitoring Stations

i. AQM AMC removed

When point AMC was removed and the values from the interpolation obtained (Table 5.6), there was no difference in values obtained for NO_x and SO_2 for all the 5 stations other than AMC. The predicted value at AMC for SO_2 and NO_x differed from the observed value by 0.41 and 0.66. The most difference in values were observed for PM_{10}, although the difference in the 5 available stations ranged between -0.21 and 0.17, the difference in predicted and observed value at AMC was 39.19.

Table 5.6: AQM AMC Removed

	PM10	NOX	SO2	NO_AMC_PM10	NO_AMC_NOX	NO_AMC_SO2	DIFF_PM10	DIFF_NOX	DIFF_SO2
PNY	74.01	36.40	15.40	74.02	36.40	15.40	0.01	0.00	0.00
KHB	56.23	35.60	14.60	56.02	35.60	14.60	-0.21	0.00	0.00
GRA	122.00	37.90	16.50	121.99	37.90	16.50	0.00	0.00	0.00
VIC	59.04	33.40	13.30	59.04	33.40	13.30	0.00	0.00	0.00
AMC	65.04	34.50	14.20	104.23	35.16	14.61	39.19	0.66	0.41
YPR	220.76	37.20	16.30	220.93	37.20	16.30	0.17	0.00	0.00
ZoneRR	86.32	35.08	14.56	98.88	35.41	14.76	12.56	0.33	0.20
ZoneS	77.47	34.38	14.04	81.36	34.35	14.00	3.89	-0.03	-0.05
ZoneBO	94.67	35.37	14.75	101.55	35.57	14.87	6.87	0.20	0.12
ZoneE	102.43	35.39	14.77	109.25	35.56	14.88	6.82	0.16	0.11

The measurements at the selected point locations in the 4 zones demonstrated that the SO_2 and NO_x values were only marginally different; SO_2 differences ranging from -0.05 and 0.2 and NO_x from -0.03 and 0.33, while the difference in predicted values of PM_{10} ranged from 3.89 to 12.56. As AMC station is closer to Zone RR, the highest difference is observed at Zone RR. The difference is values are visually represented in the Figure 5.41.

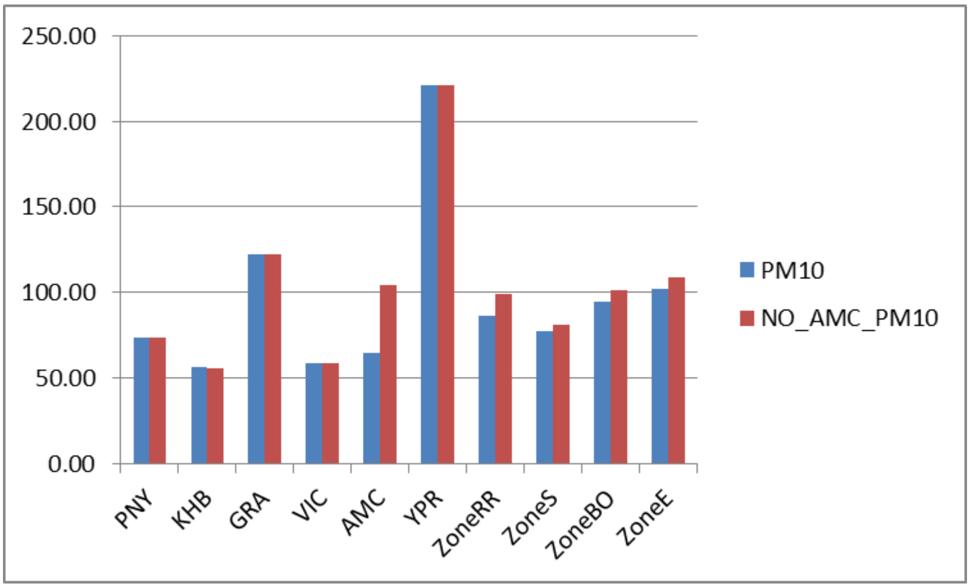

Figure 5.41: AQM AMC Removed

ii. AQM PNY Removed

The Table 5.7 provides the values when point PNY was removed and interpolation carried out. There was no difference in values obtained again for NO_x and SO_2 for all the 5 stations other than PNY. The predicted value at PNY for SO_2 and NO_x differed by -0.97 and -0.53. As for the observed PM_{10} value, GRA and AMC exhibited no difference and the difference in the other 3 stations were marginal ranging from -0.22 to 0.12. The predicted value at point PNY was higher by 44.25. The difference in predicted values of PM_{10} at the zones ranged from 0.48 to 2.91.

Table 5.7: AQM PNY Removed

	PM10	NOX	SO2	NO_PNY_PM10	NO_PNY_NOX	NO_PNY_SO2	DIFF_PM10	DIFF_NOX	DIFF_SO2
PNY	74.01	36.40	15.40	118.26	35.43	14.87	44.25	-0.97	-0.53
KHB	56.23	35.60	14.60	56.01	35.60	14.60	-0.22	0.00	0.00
GRA	122.00	37.90	16.50	121.99	37.90	16.50	0.00	0.00	0.00
VIC	59.04	33.40	13.30	59.06	33.40	13.30	0.02	0.00	0.00
AMC	65.04	34.50	14.20	65.04	34.50	14.20	0.00	0.00	0.00
YPR	220.76	37.20	16.30	220.88	37.20	16.30	0.12	0.00	0.00
ZoneRR	86.32	35.08	14.56	89.23	34.80	14.38	2.91	-0.29	-0.18
ZoneS	77.47	34.38	14.04	77.95	34.26	13.96	0.48	-0.12	-0.08
ZoneBO	94.67	35.37	14.75	96.62	35.26	14.67	1.95	-0.11	-0.07
ZoneE	102.43	35.39	14.77	103.12	35.28	14.70	0.69	-0.12	-0.08

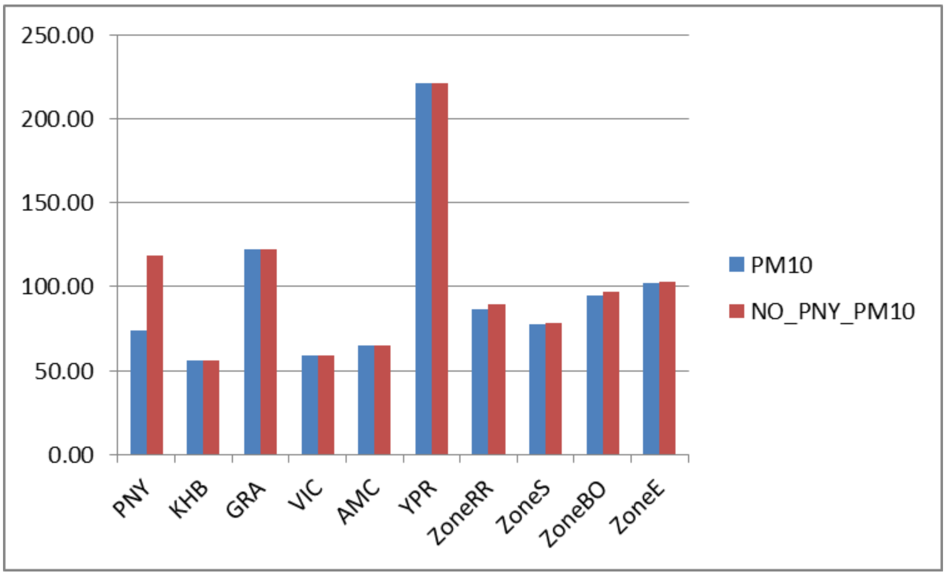

Figure 5.42: AQM PNY Removed

iii. Other AQM Stations Removed

Tables 5.8-5.11 represent the interpolated values when AQM locations KHB, GRA, YPR and VIC are removed. The difference in the predicted values of SO_2 and NO_x are low, the highest difference is observed in the PM_{10} values and especially in the point locations removed. In the observed zones, the differences in the PM_{10} values have a higher effect when YPR and VIC were removed.

Table 5.8: AQM KHB Removed

	PM10	NOX	SO2	NO_KHB_PM10	NO_KHB_NOX	NO_KHB_SO2	DIFF_PM1	DIFF_NOX	DIFF_SO2
PNY	74.00	36.40	15.40	74.06	36.40	15.40	0.06	0.00	0.00
KHB	56.00	35.60	14.60	130.43	36.08	15.33	74.43	0.47	0.73
GRA	122.00	37.90	16.50	121.99	37.90	16.50	-0.01	0.00	0.00
VIC	59.00	33.40	13.30	59.07	33.40	13.30	0.07	0.00	0.00
AMC	65.00	34.50	14.20	65.08	34.50	14.20	0.08	0.00	0.00
YPR	221.00	37.20	16.30	220.77	37.20	16.30	-0.23	0.00	0.00
ZoneRR	86.32	35.08	14.56	87.75	35.07	14.56	1.44	-0.01	0.00
ZoneS	77.47	34.38	14.04	77.96	34.35	14.03	0.49	-0.03	-0.01
ZoneBO	94.67	35.37	14.75	96.75	35.35	14.75	2.08	-0.02	0.00
ZoneE	102.43	35.39	14.77	105.34	35.39	14.79	2.91	0.00	0.02

Table 5.9: AQM GRA Removed

	PM10	NOX	SO2	NO_GRA_PM10	NO_GRA_NOX	NO_GRA_SO2	DIFF_PM10	DIFF_NOX	DIFF_SO2
PNY	74.00	36.40	15.40	74.06	36.40	15.40	0.06	0.00	0.00
KHB	56.00	35.60	14.60	56.01	35.60	14.60	0.01	0.00	0.00
GRA	122.00	37.90	16.50	98.19	35.19	14.62	-23.81	-2.71	-1.88
VIC	59.00	33.40	13.30	59.04	33.40	13.30	0.04	0.00	0.00
AMC	65.00	34.50	14.20	65.02	34.50	14.20	0.02	0.00	0.00
YPR	221.00	37.20	16.30	220.69	37.20	16.30	-0.31	0.00	0.00
ZoneRR	86.32	35.08	14.56	84.70	34.96	14.48	-1.62	-0.12	-0.08
ZoneS	77.47	34.38	14.04	76.07	34.27	13.96	-1.40	-0.11	-0.08
ZoneBO	94.67	35.37	14.75	87.80	34.75	14.32	-6.88	-0.62	-0.43
ZoneE	102.43	35.39	14.77	98.15	34.88	14.42	-4.28	-0.52	-0.36

Table 5.10: AQM YPR Removed

	PM10	NOX	SO2	NO_YPR_PM10	NO_YPR_NOX	NO_YPR_SO2	DIFF_PM10	DIFF_NOX	DIFF_SO2
PNY	74.00	36.40	15.40	73.99	36.40	15.40	-0.01	0.00	0.00
KHB	56.00	35.60	14.60	56.00	35.60	14.60	0.00	0.00	0.00
GRA	122.00	37.90	16.50	121.98	37.90	16.50	-0.02	0.00	0.00
VIC	59.00	33.40	13.30	59.01	33.40	13.30	0.01	0.00	0.00
AMC	65.00	34.50	14.20	65.00	34.50	14.20	0.00	0.00	0.00
YPR	221.00	37.20	16.30	66.92	34.94	14.40	-154.08	-2.26	-1.90
ZoneRR	86.32	35.08	14.56	67.23	34.77	14.31	-19.09	-0.31	-0.25
ZoneS	77.47	34.38	14.04	63.91	34.12	13.83	-13.56	-0.26	-0.21
ZoneBO	94.67	35.37	14.75	75.30	35.07	14.49	-19.37	-0.31	-0.26
ZoneE	102.43	35.39	14.77	73.65	34.91	14.38	-28.79	-0.48	-0.40

Table 5.11: AQM VIC Removed

	ALL_PM	ALL_NOX	ALL_SO2	NO_VIC_PM	NO_VIC_NOX	NO_VIC_SO2	DIFF_PM	DIFF_NOX	DIFF_SO2
PNY	74.00	36.40	15.40	74.02	36.40	15.40	0.02	0.00	0.00
KHB	56.00	35.60	14.60	56.00	35.60	14.60	0.00	0.00	0.00
GRA	122.00	37.90	16.50	122.00	37.90	16.50	0.00	0.00	0.00
VIC	59.00	33.40	13.30	103.21	35.48	14.91	44.21	2.08	1.60
AMC	65.00	34.50	14.20	65.14	34.50	14.20	0.14	0.00	0.00
YPR	221.00	37.20	16.30	220.92	37.20	16.30	-0.08	0.00	0.00
ZoneRR	86.32	35.08	14.56	95.38	35.64	14.98	9.07	0.55	0.41
ZoneS	77.47	34.38	14.04	101.28	35.64	14.99	23.81	1.26	0.95
ZoneBO	94.67	35.37	14.75	112.80	36.37	15.48	18.12	0.99	0.73
ZoneE	102.43	35.39	14.77	126.63	36.54	15.62	24.20	1.14	0.84

5.2.7 Summary of Interpolation

From the observations, interpolation and the cross-validation exercise, it is discerned that Bangalore may use the existing stations for SO_2 and NO_x monitoring. However, Bangalore may benefit from more increased stations for PM_{10}. It is understood that in comparison to SO_2 and NO_x monitoring, the equipment for PM_{10} monitoring is less expensive. PM_{10}, also as discussed in Chapter 3, is more harmful to health and CVD, with research increasing to study their deleterious effects on health and CVD in particular. Bangalore city would benefit from increased measuring stations for PM_{10}, in order not to miss locations with either higher levels or lower that eventually impact the exposure in neighbouring locations as demonstrated in this exercise. PM_{10} has a spatial variability due to its nature; Maantay (2007) suggests that in case of highways with heavy vehicular movement, the variability of the pollutants are limited to 150m. Lipfert (2004) states that studies based on citywide air quality suggest that local exposure, and thus individual gradients in air quality, could be very important. The question then becomes a problem of scale – it is not economically feasible to have a monitor on every block.

5.3 CVD Mortality Data

The CVD mortality data i.e. MCCD data obtained from DES was discussed in Chapter 2. As the spatial data is not recorded and this study employs a spatiotemporal methodology, the dataset was deemed unfit for the ENVHIS. The BBMP was approached for all the mortality data recorded.

The BBMP collect mortality data at various registration centres in paper forms and only recently started to digitise the paper records into digital formats to store in a central repository database. Data entry personnel have been employed to input the data from the paper records into this central database.

For the purposes of this research, the central repository centre was visited and authorisation obtained to collect the inputted records from the system. The entire database was obtained that consisted of over 1 million records. The data entry personnel are working in chronologically reverse order to input the data, and this was evident with the dataset as an initial analysis of the dataset revealed that only records of 2010-2013 were useable.

5.3.1 Data Quality

Once the data is acquired, they have to be processed by detecting and correcting inaccurate records. The term data cleansing used mainly in databases refers to identifying incomplete, incorrect, inaccurate, irrelevant parts of the data and then replacing, modifying or deleting this dirty data or coarse data (Hellerstein 2008).

The actual process of data cleansing may involve removing typographical errors or validating and correcting values against a list of entities such as rejecting any address that does not have a valid postal code or correcting records that partially match existing, known records. Data cleansing may also involve activities like harmonisation of data and standardisation of data.
Data quality has been defined as 'the fitness of data for all purposes that require it and measuring data quality requires an understanding of all intended purposes for that data' (Turner 2002). Therefore the datasets acquired was subject to testing for data quality parameters such as completeness, accuracy and other parameters as described in Table 5.12.

1. ***Amount of Data***

Data collected was input into SPSS, the variables being zone, age groups, year of death, place of death, gender and the cause of death. Cause of death was coded according to the WHO's ICD-10 classification for diseases. Codes start from A00-Z99, with CVD mortality codes ranging between I00-I99. This data was subjected to descriptive statistical analysis to determine its quality in terms of the parameters as described.

Of the n=1,090,899 records, initial analysis determined that not all records had the cause of death recorded. The absence of cause of death does not assist in the analysis of death rates attributed to specific conditions such as CVD. Hence those records were deemed unuseful for the purposes of this research. The years 2010-2013 were selected for the purposes of the study which resulted in a dataset with n=183,893 as the previous years had no cause of death recorded. This dataset was thus subjected to the assessment of data quality using the data quality parameters.

Table 5.12: Dimensions of Data Quality (Turner 2002)

2. Timeliness

Although the records obtained spanned over the years (since 1930), it is only since 2010, as mentioned previously, that Bangalore has started to robustly store them in a digital database. As the processes are in place now, with people trained to enter mortality data into the designed database, it can be inferred that Bangalore will now be in a position to adequately collate it.

3. Objectivity

Objectivity is a measure to check if information was objectively collected. It should be noted that Bangalore has two different procedures for recording deaths - home and hospital deaths. Indian law clearly states that every death has to be reported and recorded, and that all home deaths have to be certified by a doctor. All hospital deaths are reported by the hospital where the patient died. In the case of hospital deaths, a doctor also attaches the Medically Certified Cause of Death (MCCD) but they do not include the residential address of the patient. As a consequence, the spatial component of these deaths is then immediately lost. Thus, prior to commencing the data analysis in this study, deaths occurring in hospitals were classified in SPSS as ‘Institutional Deaths’ and home deaths as ‘Non-Institutional Deaths’. The Institutional Deaths accounted for 52.8% of the deaths – implying that the spatial component for over half of the records was immediately lost (Table 5.13). Although the recorded information will still assist in providing overall statistics for Bangalore, death patterns due to locational influence, if any, cannot be determined. This is valuable information which can guide environmentalists and public health officials in generating robust public health policies. Hence, the objectivity of collecting the data in usable formats has to be emphasised to all the stakeholders involved.

Table 5.13: Distribution of Deaths – Place of Death

Place of Death	Number	Percent
INSTITUTIONAL	97,075	52.8%
NON-INSTITUTIONAL	86,818	47.2%
Total	183,893	100.00%

4. *Relevance*

The data obtained is useful for analysis and interpretation, and is applicable for the intended purpose. The data includes characteristics such as age, gender, cause of death and address (only in cases of home death) that are appropriate for the purposes of this research. However, the absence of address of the deceased dying in hospitals and the short-comings in the cause-of-death recording, which are further discussed in this section, need to be improved.

5. *Completeness*

Completeness of mortality recording, according to the WHO (2013a), is a measure of the extent to which the deaths that occur in a region in a given year are registered by the civil registration system. This is calculated by the following equation:

$$YD = \frac{(RD)}{(CDR * P)} * 100$$

Where YD = Estimated death registration completeness (%)

RD = Actual number of registered deaths

CDR = Crude Death Rate (per 1,000)

P = Total population size (% by 1,000)

Applying this equation to determine completeness of death registrations in Bangalore for the year 2010 yields:

$$YD = \frac{(49{,}000)}{(8 * 8{,}400)} * 100$$

$$YD = 73\%$$

While all hospital deaths (MCCD deaths) are registered in Bangalore, home deaths require one family representative to take the death notification to the registration centre and register it. It was acknowledged by the City Council authorities that some people are not aware of the process to register and assume the death notification as a registration process. Wider awareness of the requirements for death registration is likely to improve the coverage and completeness of death registrations.

6. Accuracy

Accuracy of the data is the level to which the acquired data agrees with accepted sources of correct information. To assess for accuracy, the dataset was subjected to detailed checking for the following parameters:

i. Unknown Cause of Death

The dataset comprised causes of deaths recorded as 'Unknown' and there are missing values. This amounted to 4.1% of the total deaths (Table 5.14). The WHO (2013a) states that this is an incorrect procedure for the recording of deaths as such practice does not favour disease control and prevention programmes. It is a huge challenge for developing countries to ensure that all deaths are medically certified.

Table 5.14: Distribution of 'Unknown', and 'Missing values'

Death Causes	Frequency	Percent
Unknown	5,089	2.80%
Missing Values	2,429	1.30%
Total	7,518	4.10%

ii. Dead on Arrival

The procedure of certifying Dead on Arrival (DOA) cases differs from country to country. DOA cases are sometimes reported to the police and hence at times not included in the cause-of-death statistics. Only an autopsy can ascertain the correct cause of death and this is not always carried out. As a result, a large number of DOA cases are assigned to ill-defined or non-specific causes, which do not serve any public health purposes. Unnatural deaths that require further investigations in Bangalore are recorded as ‘Awaiting PM Report’ (PM referring to post-mortem); this accounted for 2% of the deaths in the dataset (Table 5.15).

iii. Natural and Old Age Deaths

The most challenging deaths to certify are those of older people. People suffer from various conditions as they age and if reliable medical records and lab findings are unavailable, which is typical of developing countries, ascribing the exact cause of death requires significant judgement. Sometimes the deaths of people above a certain age are simply attributed to ‘natural’ or due to ‘old age’ causes. In this dataset, the Natural Deaths (4.3%) and Old Age Deaths (2.6%) accounted for 6.9% of the total deaths (Table 5.15). The WHO (2013a) states that this is poor practice and should not be used by certifiers as the actual cause of death has to be determined for accurate death statistics.

iv. Spelling Errors

The local language in Bangalore is Kannada and the forms recording deaths are predominantly in this local language. However, the database is in English and the deaths are translated from Kannada into English by the database operators. It is presumed that some information is lost during the translation, resulting in errors in spelling and incomprehensible abbreviations. Such errors in spelling and abbreviations accounted for 6.4% of the total deaths in the dataset (Table 5.15).

Table 5.15: Distribution of Death Causes

DEATH CAUSES	FREQUENCY	PERCENTAGE
Awaiting PM Report	3,663	2%
Abbreviations	11,775	6.40%
Natural Death	7,959	4.30%
Old Age	4,856	2.60%
TOTAL	28,253	15.30%

v. *Ill-Defined Causes of Deaths*

The dataset included a list of ill-defined causes of deaths such as symptoms and signs, R00-R99, J81, etc. Although these are used for coding deaths, ideally they should be frequently monitored so as to reduce their vague connotations. In general, it is recommended that the proportion of deaths coded according to these ill-defined categories should not exceed 10% of all deaths in the age group of 65 years and above. Also for those under the age of 65, it should account for only 5% of deaths. On inspection, for Bangalore, this did not exceed the recommended percentage, but much can be achieved by improving the coding practice.

Following a test for accuracy and by identifying all the shortcomings, 19.4% of the overall records were deemed incomplete for use in this research (Table 5.16). Table 5.16 also provides the distribution of deaths according to the Institutional and Non-institutional deaths. It can be concluded that the MCCD deaths recorded by hospitals (Institutional), although appearing to be better recorded than home deaths, still contribute to 10.3% of overall errors. The percentage of Unknown, Missing values, Old Age, and Natural Death individually contribute to less than 1%. Spelling errors and abbreviations made the major contribution to errors. These errors can be minimised through the appropriate training of coders on cause-of-death recording and training of database operators to input data accurately.

Table 5.16: Distribution of death causes according to place of death

DEATH CAUSES	INSTITUTIONAL	NON-INSTITUTIONAL	TOTAL
Unknown	1,050	4,039	5,089
	1.10%	4.60%	2.80%
Awaiting PM Report	1,292	2,371	3,663
	1.30%	2.70%	2.00%
Spelling Errors and Abbreviations	6,268	5,507	11,775
	6.50%	6.30%	6.40%
Missing Values	743	1,686	2,429
	0.80%	1.90%	1.30%
Natural Death	249	7,710	7,959
	0.30%	8.90%	4.30%
Old Age	289	4,567	4,856
	0.30%	5.30%	2.60%
TOTAL PERCENTAGE	10.30%	29.70%	19.40%

7. Access Security

The mortality database is protected against unauthorised access through appropriate security measures and password controls. For the purposes of this research the BBMP provided data where the rights of the individuals were protected by removing all identifiable variables, such as name of the individual being replaced by a unique ID, Date of Birth being removed and replaced by age, and full address of the deceased being replaced by only the corresponding ward/zone.

5.3.2 Summary of Mortality Data Assessment

It is concluded from this assessment that Bangalore has a system that is functional but could be improved. Having identified the data quality issues, it is determined that if there is a focus on improving the elements that can be easily rectified, Bangalore will see an improved mortality database which will provide credible and trustworthy information that will assist in determining any patterns or trends in the deaths. For example, certifying deaths by the 'cause-of-death' is important as it describes and explains levels and trends. Emerging diseases and conditions can be identified and the scale of how different groups are affected by the burden of specific diseases can be tracked. This will then guide the priorities for intervention programmes and the decisions on directing and/or allocating resources according to areas of priority. According to the WHO (2013a), due to the many important public health uses to which the cause of death statistics are put, the accurate diagnosis of the cause of death should be ensured and coded according to international standards.

Recommendations based on WHO guidelines for improving cause of death coding are provided in a generalisable data quality framework developed for Bangalore (Figure 5.43). The implementation of the proposed policies will aid Bangalore in improving data collection that will in turn result in recording unambiguous and correct cause-of-death information.

5.4 Data Quality Framework

The data quality assessment was carried out in 3 stages. This consisted of the assessment of:

- Demographic Data
- Air Pollution Data
- Mortality Data

The limitations in the datasets were identified. Based on this, a Data Quality Framework was developed (Figure 5.43) that includes the 3 areas of assessment and provides recommendations that will strengthen the data collection and data quality in Bangalore. The recommendations are based on the WHO guidelines for strengthening civil registration and vital statistics for births, deaths and causes of death. This framework is generalisable and can be applied to other cities in India and with certain modifications to other developing cities.

5.4.1 Record Age-Specific Breakdown of Population

The demographic data was assessed according to the specified parameters. The age-wise breakdown of the population is recommended to aid in the calculation of age-standardised deaths.

5.4.2 Increase PM Monitoring

The data quality assessment was carried out on air-pollution data. To overcome the limitation of the limited number of stations, spatial interpolation methods were proposed to obtain pollution levels at unmonitored locations. A validity assessment was also carried out to determine the margin error from the interpolation assessment. It was determined that Bangalore would benefit from wider PM monitoring.

5.4.3 Introduction of Verbal Autopsy Procedures

The number of Unknown cases in mortality coding is high in the dataset. A number of factors could lead to recording deaths in this manner, the most prominent ones being the coding practice and lack of training and qualifications. Where the cause of death is not known, verbal autopsy (VA) procedures can be used to determine the cause of death; Verbal Autopsy is a procedure where carers or family members are asked using a standard questionnaire about signs and symptoms that led to the death of the person (CGHR 2014). The sequence of causes that led to the death can then be determined by a MCCD trained practitioner and entered into the death certificate. This process will reduce the number of deaths recorded as 'Unknown' or 'Missing Values' that contribute to almost 4.1% of deaths in this dataset.

5.4.4 Introduction of Automated Cause of Death Recording

Many countries, such as the UK and US, use automated coding programs such as ACME (Automated Classification of Medical Entities), IRIS (a language-independent and MICAR (Mortality Indexing, Classification and Retrieval) primarily to (i) to introduce consistent and rapid assignment of underlying cause-of-death coding with reduced needs for manpower training; and (ii) to allow better utilisation of medical information on death certificates for multiple cause-of-death analyses (Israel 1990; O'Carroll 2003). These computer programmes enable coders to select an accurate underlying cause of death, henceforth minimising the number of subjective decisions a coder normally makes. Introduction of this tool in Bangalore will enhance the quality of the dataset by tackling the problem of inconsistency among coders and standardise the production of mortality statistics.

5.4.5 Increase In MCCD Coding Training And Qualifications

Mortality coding is a highly specialised task that requires thorough understanding of the rules for determining the underlying cause of death and for assigning codes. The level of knowledge and understanding of the coder is a key determinant of the accuracy of the resulting data. It is thus essential for coders to be qualified professionals. An understanding of medical terminologies and medical sciences will ensure effective coding and will aid the coders in selecting the appropriate codes for the underlying cause of death as per the requirements of the ICD-10. Where coders do not have the opportunity to undergo such training, the WHO has developed an electronic self-training tool (WHO 2014b). Also, since the highest percentage of errors in the dataset is a result of spelling errors and abbreviations, some investment in cause-of-death training would result in considerable improvement of the quality of the dataset.

Figure 5.43: Data Quality Framework (extended from WHO 2013a)

5.4.6 Introduction of WHO Form for MCCD

The WHO recommends the use of their standardised Cause-of-Death Recording Form for use in death recording. As Bangalore already has its own standard form for recording deaths, amendments that need to be incurred to improve the recording of data is that forms need to compulsorily include the characteristics described in Table 5.17.

Table 5.17: Characteristics of Cause of Death recording

Characteristics of the event	Characteristics of the deceased
Date of occurrence	Date of birth and age (derived)
Date of registration	Sex
Place of occurrence	Marital status
Place of registration	Place of usual residence
Locality of occurrence (derived)	Locality of residence (derived)
Urban or rural occurrence (derived)	Urban or rural residence (derived)
Cause(s) of death	
Certifier and type of certification (derived)	

If these fields are made mandatory at the time of recording deaths, the risk of losing the spatial location of the deceased will be minimised. This will aid in determining the spatial pattern of disease, if any, to guide policies and interventions.

5.4.7 Regular Evaluation

It is good practice that the performance of coders should be systematically evaluated on a regular basis to ensure good quality of coding. Additional training or guidance can be provided when inconsistencies (or errors) are identified. Routine internal reviews to check the quality of coding will highlight any weaknesses and, with adequate training, will improve the overall quality of deaths recording.

5.4.8 Increase in MCCD Awareness

It is important for the different stakeholders such as coders, practitioners, physicians and related personnel to understand the purposes of collecting and using cause-of-death information. Appropriate training and awareness will influence the quality of the coded data with a possible substantial impact on its quality.

5.4.9 Database Integration with Levels of Access/Security

It has been noted that there is considerable duplication of data in Bangalore with both BBMP and DES having databases of mortality data. As databases have powerful capabilities of integration, security and access, it is recommended that one central database be utilised to digitally record all deaths. Appropriate access controls can then ensure access rights to the necessary fields of the data.

5.5 Summary

An assessment of the current data quality issues in recording mortality events has determined that Bangalore has a system that has a completeness of 73%. The accuracy of the dataset has resulted in 19.4% of the records being unusable as the cause-of-death recording is either absent or inaccurate. As the geographic distribution of deaths is vital to determine the trends and patterns of deaths, it is necessary that all records have the address of the deceased accurately recorded; the current MCCD recording practice in Bangalore although focuses on determining the cause-of-death, does not prioritise the address of the patient, hence losing valuable information for over 52% of the records.

Bangalore could address these inadequacies by developing an improvement plan; by adopting the components of the framework described, a drastic improvement in data quality can be achieved. As the resources are already available, with very minimal costs, a robust health information management system can be advocated and maintained. Avoiding duplication of the data will result in cost-savings which can then be channelled into more public health interventions.

Countries such as Thailand (Tangcharoensathien *et al*. 2006), Sri Lanka (Rampatige *et al*. 2009) and Iran (Khosravi *et al*. 2008) have in recent years conducted an assessment of their systems that highlighted their shortcomings such as absence of a strong legislation for registration of births and deaths, decentralised systems with wide differences in practice, absence of usage of the International Form for MCCD, incorrect coding of cause of death, paper based recording of deaths, lack of awareness among citizens and training for coding cause of death accurately. These countries reviewed their policies to strengthen their Health Information Management System as a priority. The areas for improvement such as hospital death certification, deaths occurring outside the hospitals, coverage and completeness of registration, ICD-10 compliance practices for death certification, review of forms used for registration were recommended. The countries developed a set of recommendations and a feasible set of actions that was likely to have a significant impact on the data quality. The countries learned a lot from the assessments which became building blocks from which they developed strategic and long-term improvement plans for their systems.

Simple measures to improve the mortality recording system in Bangalore will result in reliable and accurate mortality statistics. The resulting database can then be imported into the ENVHIS which will enable mapping of the deaths in the city and highlight any hotspots due to specific diseases or certain causes of death. This generalisable framework can then also be duplicated in other major cities in India to enable the government to better regulate health policies and interventions.

The next chapter will demonstrate the association of air pollution and CVD using non-spatial analytical methods and spatial analysis.

Chapter 6: Association of Air Pollution and CVD

6.1 Overview

Several long-term studies (Dockery *et al*. 1993, Pope *et al*. 2004) and short-term studies (Samet *et al.* 2000, Dominici *et al.* 2003, Katsouyanni *et al.* 2001) have investigated the associations between daily concentrations of pollutants and in the increase in the number of cardiovascular events. These studies have found associations for gaseous pollutants such as NO_x, O_3, SO_2 and also particulate matter PM<10µm and/or PM<2.5µm.

This chapter will demonstrate the analysis of CVD and air pollutants NO_x, SO_2 and PM_{10} in Bangalore. The analysis will be performed as Aspatial Analysis using SPSS and Spatial Analysis using the ENVHIS.

6.2 Mortality by Zone

In Chapter 2, the CVD statistics with the hospital records was discussed. Although this provided a statistical interpretation of the disease for Bangalore, the extent of the problem with regards to location could not be determined. To assist in the spatial identification of the disease, the deaths where the addresses are recorded were obtained from BBMP. The dataset consisted of 183,893 records of which 86,818 (52.57%) records were Non-Institutional records (Table 6.1 and Figure 6.1). This is the data that is used in this analysis.

Table 6.1: Characteristics of Mortality by place of death for years 2010-2013

PLACE OF DEATH	ALL DEATHS	NON-CVD	PERCENT	CVD	PERCENT
INSTITUTIONAL	97,075	67,233	55.58%	29,842	47.43%
NON-INSTITUTIONAL	86,818	53,743	44.42%	33,075	52.57%
Total	**183893**	**120976**	**100%**	**62917**	**100%**

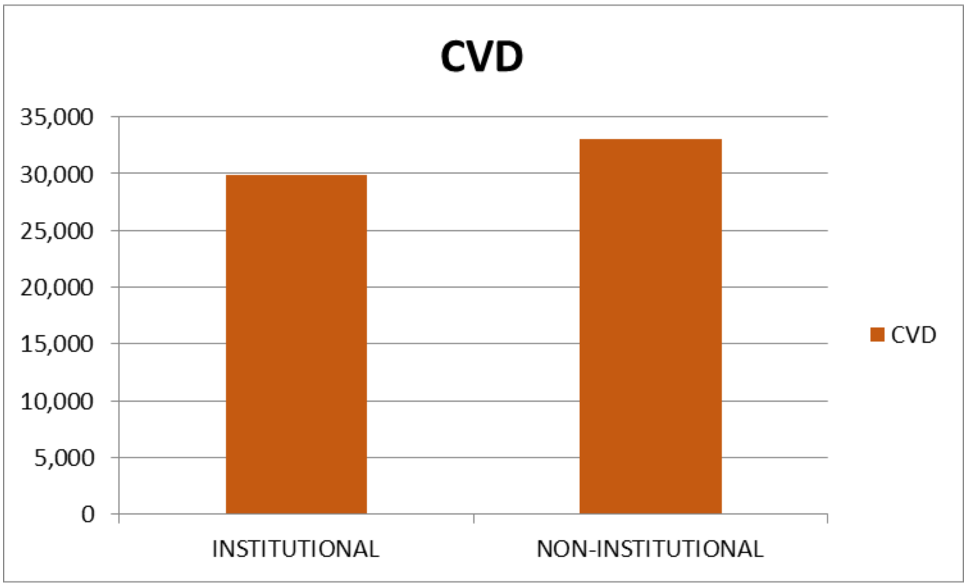

Figure 6.1: Deaths by place of death

6.3 Descriptive Analysis of CVD Mortality

The total Non-Institutional deaths over the years 2010-2013 were 86,818 of which 33,075 deaths were due to CVD and 53,743 deaths were due to all other causes. CVD over the four years on an average contributed to 38.10% of all deaths. In the UK, in 2012, CVD accounted for 28% of all deaths (Townsend *et al*. 2014).

Where a person lives can be a determinant of health and well-being. Numerous studies have highlighted the proximity to polluting sources, highways, etc. and the risk of CVD. Table 6.2 and Figure 6.2 represent the mortality distribution by zones. Zones West and East had the highest mortality followed by zones South and Mahadevapura. However, when the percentage of total deaths is considered, CVD deaths in zone East was the highest contributing to 50% of the total deaths.

Table 6.2: Non-Institutional Mortality by Zones for years 2010-2013

ZONES	ALL DEATHS	NON-CVD	PERCENT	CVD	PERCENT
BOMMANAHALLI	2,873	1,641	57.12%	1,232	42.88%
BYATARAYANPURA	5,263	3,150	59.85%	2,113	40.15%
DASARAHALLI	3,111	1,780	57.22%	1,331	42.78%
EAST	15,783	7,737	49.02%	8,046	50.98%
MAHADEVAPURA	6,359	3,755	59.05%	2,604	40.95%
RR NAGAR	4,572	3,168	69.29%	1,404	30.71%
SOUTH	23,428	15,998	68.29%	7,430	31.71%
WEST	25,429	16,514	64.94%	8,915	35.06%
	86,818	**53,743**	61.90%	**33,075**	38.10%

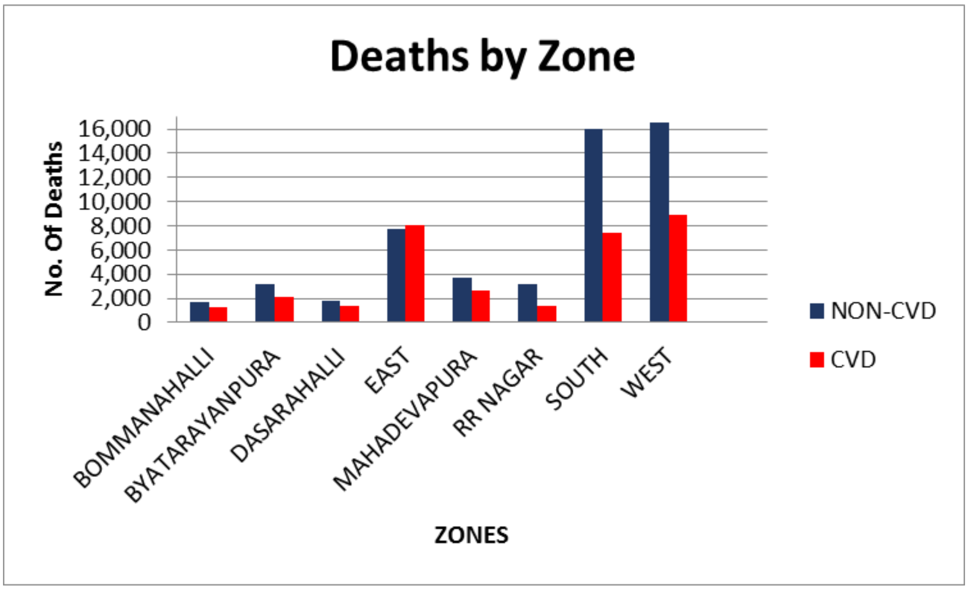

Figure 6.2: Deaths by zone

6.3.1 Rate of Death

Mortality rates will provide an exact understanding of the frequency of deaths in a particular zone. It provides a general indication of the health status of a geographic area and assists stakeholders in healthcare planning for the population of that area. Hence, understanding the CVD mortality rate will enable the healthcare planning and allocating of resources and policies for an affected area in Bangalore. Mortality rate from a particular cause of death is calculated as number of deaths in a given population per 100,000 during a specified time period (Indrayan 2012) and uses the formula:

$$Rate\ of\ Death = \frac{\text{Number of deaths from CVD in Year}}{\text{Estimated population in Year}} * 100{,}000$$

The mortality death rate for CVD was calculated for Bangalore for the year 2011 using the total (Institutional and Non-Institutional) CVD deaths:

$$Rate\ of\ Death = \frac{16{,}418}{8{,}418{,}567} * 100{,}000$$ = 195 deaths/100,000 people

This resulted in CVD Mortality rate of 195 deaths per 100,000 people in Bangalore. The mortality rate per zone was also calculated and is provided in Table 6.3. The zone West had the highest CVD mortality rate of 189 deaths per 100,000 people followed by zone East with 131 deaths per 100,000. These rates however, are to be considered only as an indication, as these are only representative of non-institutional deaths. The institutional deaths are not included in this table.

Table 6.3: Mortality Rate per Zone

ZONE	2011_POP	2011_CVD	CVD RATE OF DEATH
BOMMANAHALLI	921296	299	32
BYATARAYANAPURA	540906	603	111
DASARAHALLI	449065	330	73
EAST	1648006	2,156	131
MAHADEVAPURA	875291	549	63
RR NAGAR	752297	359	48
SOUTH	1957507	1,997	102
WEST	1274199	2,413	189

6.3.2 Disability Adjusted Life Years

Disability Adjusted Life Years (DALY) measures the losses from disability or death with diseases accounting for more DALY having a higher public health impact (Murray and Lopez

2006). Health measures are then taken to reduce the number of DALY. The DALY has become a key measure employed by the WHO and countries generally perform DALY calculations to assess and monitor their population's health and to set priorities within their health sector.

6.3.2.1 DALY formula

DALY are the sum of years of life lived with disability (YLD) and Years of potential life lost (YPLL), per disease category or outcome, and per age and gender:

$$DALY = YLD + YPLL$$

The YLDs are the morbidity component of the DALYs, and are proportional to the number of incident cases and the severity of the disease:

$$YLD = \text{Number of Cases} * \text{Disease Duration} * \text{Disability Weight}$$

The YPLLs are the mortality component of the DALYs, and are proportional to the number of deaths and the average age of death. As the comprehensive morbidity data was not available for Bangalore, only the YPLL was calculated.

Years of potential life lost (YPLL), also sometimes referred to as potential years of life lost (PYLL) is defined as an estimate of the average years a person would have lived if he or she had not died prematurely (Gardner and Sanborn 1990). Hence it can be described as a measure of premature mortality. PYLL gives more weight only to deaths that occur among younger people.

6.3.2.2 Calculation

The years of potential life lost is calculated by setting an upper reference age, this reference age normally corresponds to the life expectancy of the study population. The reference age in developed countries is usually set at 75, but this is lower in developing countries. PYLL is expressed with respect to the reference age [75].

For the purposes of this analysis, an upper reference age was first set to calculate the potential years of life lost. The upper reference age refers to the life expectancy of the Indian population, which has been determined to be 66.21 years (Chauhan and Aeri 2013). In order to calculate an individual PYLL, the difference between the person's age at death and the reference age is calculated. If the person's age at death is higher than the reference age, it is set at 0. There is no negative PYLL, for example:

1. Reference age = 66; Age at death = 60; PYLL[66] = 66 - 60 = 6
2. Reference age = 66; Age at death = 6 months; PYLL[66] = 66 - 0.5 = 65.5
3. Reference age = 66; Age at death = 70; PYLL[66] = 0

To calculate the PYLL for the population over a certain period, the individual PYLLs are summed for all individuals in that population who died in that year. This was undertaken as a cause-specific mortality for Bangalore and it was determined that 2.1 million productive years were lost due to CVD during 2010-2013.

Because PYLL gives more weight to deaths among younger individuals, it is the favoured metric among those who wish to draw attention to those causes of death that are more common in younger people.

6.3.3 Inferential Statistics

This section demonstrates how inferential statistics can be carried out on the data to determine if there is a statistical association between air pollutants and CVD. Inferential statistics make predictions or inferences about a population from observations and include linear regression analyses, logistic regression analyses, ANOVA, correlation analyses, structural modelling, etc.

Regression: To establish any associations that may exist between the level of pollutants and CVD occurrences, regression analysis was carried out. Regression analysis is a statistical process for the investigation of the relationships between variables. Regression involves several techniques for modelling and analysing several variables to establish the causal effect of one variable upon another (Sykes, 1993). As a categorical variable (CVD) will be predicted from a set of independent variables (air pollutants, age, place of residence, gender), logistic regression is employed. Logistic regression is used for predicting a categorical variable that is usually dichotomous from a set of independent variables (predictors). Logistic regression unlike linear regression analysis estimates the probability of an event occurring. In health research, logistic regression is popularly used where the dichotomous dependent variable is whether or not a patient has a disease (Wuensch 2014).

All the Non-Institutional records were input into the SPSS for analysis. The CVD was set as the dependent variable and is a dichotomous variable i.e. either CVD or Non-CVD. The independent variables were: pollutants – PM, SO_2 and NO_x; age groups; zone of residence; gender. The interpolated air pollution values as explained in for every zone in Bangalore is collected from the ENVHIS and inputted into the SPSS for every zone.

The overall aim of this analysis is to obtain a representation of the patterns of association between CVD and the independent variables by:

- Exploring separate groups of independent variables that can predict CVD occurrence and studying the interactions between those in each group of variables that could be of significant importance in the prediction.
- Observing the cumulative contribution of the subset model towards the prediction of CVD occurrence when put into an overall predictive model.

Subsequent to studying the emergent patterns from the initial set of analysis, inferential statistical analysis was performed to further investigate the relationship between the earlier mentioned independent factors (age, gender, zone and air pollution parameters) and the nature of death (i.e., CVD or non-CVD). As the dependent variable (nature of death) is categorical in nature, the form of inferential statistical analysis that was deemed appropriate was Logistic Regression analysis.

Logistic Regression was conducted in two phases. First, a simple Bivariate Logistic Regression analysis was conducted to determine the relationship between each of the predictors and the dependent variable. A series of bivariate analyses was carried out in order to explore the different crude associations. This was then followed by multivariable logistic regression analysis.

The second phase of the inferential analysis was designed as a follow-up to the first phase of the analysis process, and involved the selection of variables that were statistically significant ($p<0.05$) in the initial inferential statistical analysis. Following the selection process, the eligible variables/factors were then analysed through a Multivariable Logistic Regression model to test their relationship with the occurrence of CVD mortality in order to explore their predictive strength. The robustness of the emerging model was assessed with the Omnibus Chi-square statistical test, with $p<0.05$ indicating good-fit. The contributions of individual factors to the goodness-of-fit were further assessed through a Wald test, with the significant contribution of each individual variable indicated by odds ratios, 95% Confidence Intervals and p-values.

The Multivariable Logistic Regression model was designed based on the results of the Simple Logistic Regression which indicated that dependent variables such as age, zone of residence, SO_2, NO_x and PM_{10} levels all associate significantly with occurrence of CVD for certain years of the analysis. The models for the years 2010-2013 explore the relationship between the occurrence of CVD against independent variables, pollutants SO_2, NO_x, PM_{10}, age groups, place of residence and gender and are presented in Tables 6.4-6.7.

Table 6.4 shows the details of the variables in the parsimonious model fitted for the prediction of cardiovascular mortality [χ^2 (21, N=23,102) = 1493.54, $p<0.001$; Hosmer & Lemenshow: $p<0.001$], considering 21 degrees of freedom and a total of 23,102 samples for 2010.

Table 6.4: Adjusted Odds Ratios (OR)*, 95% Confidence Intervals (CI) and p-Values of the Multivariable Logistic Regression Model For Cardiovascular Mortality in Bangalore in 2010

Variable		**Co-efficients**	**OR (95% CI)**	***p*-value**
Age at death				0.000
	0-4	0.000	1	
	5-14	-1.145	0.318 (0.182 - 0.556)	0.000
	15-24	-0.666	0.514 (0.345 - 0.765)	0.001
	25-34	-0.990	0.371 (0.285 - 0.485)	0.000
	35-44	-0.854	0.426 (0.340 - 0.533)	0.000
	45-54	-0.217	0.805 (0.658 - 0.985)	0.035
	55-64	0.232	1.262 (1.041 - 1.529)	0.018
	65-74	0.346	1.413 (1.172 - 1.704)	0.000
	75-84	0.272	1.312 (1.091 - 1.579)	0.004
	85-94	0.281	1.324 (1.100 - 1.595)	0.003
	95+	0.157	1.170 (0.965 - 1.419)	0.110
Zones				0.000
	BOMMANAHALLI	0.000	1	
	BYTARAYANAPURA	0.142	1.152 (0.982 - 1.352)	0.082
	DASARAHALLI	-0.036	0.964 (0.817 - 1.138)	0.669
	EAST	0.240	1.271 (1.082 - 1.494)	0.004
	MAHADEVAPURA	0.245	1.278 (1.171 - 1.394)	0.000
	RR NAGAR	0.383	1.467 (1.229 - 1.751)	0.000
	SOUTH	-0.572	0.564 (0.488 - 0.653)	0.000
	WEST	-0.407	0.665 (0.608 - 0.728)	0.000
Gender				0.244
	Male	0.000	1	
	Female	0.034	1.035 (0.977 - 1.095)	0.244
Pollutants				
	SO_2	-1.895	0.150 (0.082 - 0.277)	0.000
	NO_x	1.163	3.199 (2.099 - 4.877)	0.000
	PM_{10}	0.004	1.004 (1.002 - 1.006)	0.000

Variables including age at death, place of residence, NO_x and PM_{10} concentrations were statistically related to cardiovascular mortality in the fitted model ($p<0.05$), while gender was only found to be a confounder.

Table 6.5 shows the details of the variables in the parsimonious model fitted for the prediction of cardiovascular mortality [χ^2 (21, N=22,600) = 986.311, $p<0.001$; Hosmer & Lemenshow: $p<0.001$], considering 21 degrees of freedom and a total of 22,600 samples for 2011.

Table 6.5: Adjusted Odds Ratios (OR)*, 95% Confidence Intervals (CI) and p-Values of the Multivariable Logistic Regression Model For Cardiovascular Mortality in Bangalore in 2011

Variable		**Co-efficients**	**OR (95% CI)**	***p*-value**
Age at death				0.000
	0-4	0.000	1	
	5-14	-1.216	0.296 (0.167 - 0.527)	0.000
	15-24	-0.582	0.559 (0.364 - 0.858)	0.008
	25-34	-1.177	0.308 (0.234 - 0.406)	0.000
	35-44	-0.747	0.474 (0.378 - 0.594)	0.000
	45-54	0.078	1.081 (0.882 - 1.324)	0.453
	55-64	0.273	1.314 (1.083 - 1.594)	0.006
	65-74	0.360	1.433 (1.187 - 1.731)	0.000
	75-84	0.427	1.533 (1.272 - 1.847)	0.000
	85-94	0.366	1.441 (1.196 - 1.738)	0.000
	95+	0.241	1.273 (1.049 - 1.545)	0.015
Zones				0.000
	BOMMANAHALLI	0.000	1	
	BYTARAYANAPURA	-0.238	0.788 (0.648 - 0.959)	0.017
	DASARAHALLI	0.565	1.760 (1.523 - 2.034)	0.000
	EAST	0.484	1.622 (1.389 - 1.893)	0.000
	MAHADEVAPURA	0.603	1.828 (1.678 - 1.992)	0.000
	RR NAGAR	0.202	1.224 (0.951 - 1.576)	0.117
	SOUTH	0.049	1.051 (0.912 - 1.210)	0.494
	WEST	-0.290	0.748 (0.690 - 0.812)	0.000
Gender				0.002
	Male	0.000	1	
	Female	0.090	1.094 (1.033 - 1.159)	0.002
Pollutants				
	SO_2	0.000	1.000 (0.989- 1.010)	0.950
	NO_x	-0.819	0.441 (0.367 - 0.530)	0.000
	PM_{10}	0.513	1.670 (1.384 - 2.015)	0.000

Variables including age at death, place of residence, gender and PM_{10} concentrations were statistically related to cardiovascular mortality in the fitted model ($p<0.05$).

Table 6.6 shows the details of the variables in the parsimonious model fitted for the prediction of cardiovascular mortality [χ^2 (21, N=23,389) = 1562.798, $p<0.001$; Hosmer & Lemenshow: $p<0.001$], considering 21 degrees of freedom and a total of 23,389 samples for 2012.

Table 6.6: Adjusted Odds Ratios (OR)*, 95% Confidence Intervals (CI) and p-Values of the Multivariable Logistic Regression Model For Cardiovascular Mortality in Bangalore in 2012

Variable		Co-efficients	OR (95% CI)	*p*-value
Age at death				0.000
	0-4	0.000	1	
	5-14	-0.767	0.464 (0.254 - 0.848)	0.012
	15-24	-0.987	0.373 (0.240 - 0.578)	0.000
	25-34	-1.300	0.273 (0.203 - 0.366)	0.000
	35-44	-0.987	0.373 (0.296 - 0.469)	0.000
	45-54	-0.096	0.908 (0.741 - 1.113)	0.355
	55-64	0.151	1.163 (0.958 - 1.412)	0.126
	65-74	0.325	1.384 (1.145 - 1.673)	0.001
	75-84	0.298	1.348 (1.118 - 1.625)	0.002
	85-94	0.237	1.267 (1.050 - 1.529)	0.013
	95+	0.120	1.127 (0.928 - 1.369)	0.229
Zones				0.000
	BOMMANAHALLI	0.000	1	
	BYTARAYANAPURA	0.027	1.027 (0.869 - 1.214)	0.750
	DASARAHALLI	-0.685	0.504 (0.426 - 0.596)	0.000
	EAST	-0.285	0.752 (0.626 - 0.904)	0.000
	MAHADEVAPURA	0.219	1.244 (1.130 - 1.370)	0.000
	RR NAGAR	-0.095	0.910 (0.742 - 1.116)	0.360
	SOUTH	-0.177	0.838 (0.733 - 0.957)	0.010
	WEST	-0.729	0.482 (0.438 - 0.531)	0.000
Gender				0.281
	Male	0.000	1	
	Female	0.032	1.032 (0.974 - 1.094)	0.281
Pollutants				
	SO_2	-0.060	0.942 (0.909 - 0.976)	0.001
	NO_x	-0.657	0.519 (0.489 - 0.550)	0.000
	PM_{10}	0.023	1.023 (1.020 - 1.026)	0.000

Variables including age at death, place of residence and PM_{10} concentrations were statistically related to cardiovascular mortality in the fitted model ($p<0.05$), while gender was only found to be a confounder.

Table 6.7 shows the details of the variables in the parsimonious model fitted for the prediction of cardiovascular mortality [χ^2 (21, N=17,727) = 820.593, $p<0.001$; Hosmer & Lemenshow: $p<0.001$], considering 21 degrees of freedom and a total of 17,727 samples for 2013.

Table 6.7: Adjusted Odds Ratios (OR)*, 95% Confidence Intervals (CI) and p-Values of the Multivariable Logistic Regression Model For Cardiovascular Mortality in Bangalore in 2013

Variable		**Co-efficients**	**OR (95% CI)**	***p*-value**
Age at death				0.000
	0-4	0.000	1	
	5-14	-0.965	0.381 (0.183 - 0.792)	0.010
	15-24	-0.898	0.407 (0.240 - 0.693)	0.001
	25-34	-1.334	0.263 (0.187 - 0.370)	0.000
	35-44	-0.801	0.449 (0.346 - 0.583)	0.000
	45-54	-0.119	0.887 (0.702 - 1.122)	0.319
	55-64	0.135	1.144 (0.913 - 1.433)	0.242
	65-74	0.261	1.299 (1.043 - 1.617)	0.020
	75-84	0.265	1.304 (1.050 - 1.618)	0.016
	85-94	0.153	1.165 (0.937 - 1.448)	0.169
	95+	0.186	1.204 (0.962 - 1.509)	0.105
Zones				0.000
	BOMMANAHALLI	0.000	1	0.483
	BYTARAYANAPURA	0.062	1.064 (0.895 - 1.264)	0.002
	DASARAHALLI	-0.283	0.753 (0.628 - 0.904)	0.000
	EAST	-0.540	0.583 (0.461 - 0.737)	0.000
	MAHADEVAPURA	0.575	1.778 (1.608 - 1.966)	0.000
	RR NAGAR	1.500	4.483 (3.810 - 5.276)	0.000
	SOUTH	-0.724	0.485 (0.411 - 0.571)	0.000
	WEST	-0.970	0.379 (0.341 - 0.422)	0.000
Gender				0.511
	Male	0.000	1	
	Female	-0.022	0.978 (0.916 - 1.045)	0.511
Pollutants				
	SO_2	-1.569	0.208 (0.113 - 0.384)	0.000
	NO_x	0.206	1.229 (1.123 - 1.345)	0.000
	PM_{10}	0.023	1.023 (1.020 - 1.027)	0.000

Variables including age at death, place of residence, NO_x and PM_{10} concentrations were statistically related to cardiovascular mortality in the fitted model ($p<0.05$), while gender was only found to be a confounder in 2013.

6.3.4 Summary of Inferential Statistics

The results show that individuals within the age groups at death of, 65-74, 75-84, 85-94 years all had approximately a 1-fold increase in the likelihood of dying of CVD for the years between 2010 -2013. The year 2011 also showed a statistical association to the age group 55-64 with an odds ratio of 1.314.

In terms of place of residence, in 2010, the zones East, Mahadevapura and RR Nagar were all statistically related to CVD mortality. In 2011, the zones East, Mahadevapura and Dasarahalli showed a statistical association. In 2012, only zone Mahadevapura had a statistical association with an odds ratio of 1.244. Finally, in 2013 zones Mahadevapura and RR Nagar were statistically related to CVD mortality with odds ratio of 1.778 and 4.483, respectively. Zone Mahadevapura has consistently had a statistical association over the four years under consideration.

In terms of air pollution exposure, after controlling for the effect of age, gender and place of residence, the results show that, in 2010, with every increase of $1 \mu g/m^3$ in NO_x concentration there is a significant increase in the chances of dying of CVD, with a 3.2 folds increase in the likelihood of CVD mortality. In 2013, with every $1 \mu g/m^3$ increase in the level of NO_x concentration there is a significant increase in the likelihood of cardiovascular mortality with OR = 1.229.

In terms of PM_{10} exposure, and subsequent to controlling for the effect of age, place of residence and gender, the results show that with every increase of $1 \mu g/m^3$ in PM_{10} concentration there is an increase in the chances of dying of CVD which, for the 4 years under consideration, are as follows:

- 2010: OR = 1.004
- 2011: OR = 1.670
- 2012: OR = 1.023
- 2013: OR = 1.023

6.4 Spatial Analysis

Spatial analysis can be described as a set of techniques that aim to determine relationships between spatial and non-spatial variables. Spatial epidemiological analysis includes the determination of spatial patterns, identification of disease clusters and the explanation or prediction of disease risk (Pfeiffer 2008).

Heywood (2006) states that the spatial analysis techniques in GIS provide concepts and transformations in such a way that is not possible with other techniques. A vast range of spatial analysis techniques can be carried out on the data that may include simple queries or more complex geospatial analyses. The results of the analyses can be viewed on the database table or in the form of charts, graphs or reports. Examples of spatial analysis techniques include:

- Buffer Analysis
- Overlay Analysis
- Geocoding
- Spatial Interpolation
- Spatial Regression
- Hot Spot Analysis

The spatial analysis was carried out on the data in the ENVHIS using the techniques described in the following sub-sections.

6.4.1 Geocoding

Geocoding is a method of classifying geographic location. It involves the process of assigning x and y coordinates based on the actual latitude and longitude of the earth's surface where the location is sited (Summerhayes *et al.* 2006). Geocoding technology often resides within the more complex geographical information systems (GIS) that manage location-based and related data.

In the ENVHIS addresses are converted to features on the map through the geocoding process (Figure 6.3). The steps involve translating the address entry, searching for the address in the reference data and delivering it as a feature on the map.

There are different types of geocoding process such as point entry, street address, etc. In this geocoding process, due to the nature and availability of the data, the location assigned to a particular address is the polygon representing the geographic unit. Location within the unit is not specified but analysis is carried out using the data associated with the geographic unit.

Figure 6.3: Geocoding by polygon

6.4.2 Dot Density Maps

Once the geocoding process is complete, the dot density maps are created. Dot density maps or dot maps represent the geographic distribution of discrete phenomena using point symbols, most commonly identical dots. These maps particularly provide an understanding of the distribution of the phenomena under consideration by comparing relative densities of different regions on the map. There are two kinds of dot density maps:

- One-to-one maps
- One-to-many maps

In the one-to-one dot density maps each point on the map corresponds to a single incidence of the mapped phenomena. One-to-many dot density maps, on the other hand, represent a pre-determined number of incidences of the mapped phenomena. To represent the CVD deaths, the one-to-many dot density maps are used as the data has been aggregated to an enumeration unit and there are many points within the units for representation.

The four important design considerations for one-to-many dot density maps are:

- Units of aggregation
- Dot size
- Dot values
- Dot placement

The unit of aggregation is at zonal level (Figure 6.4). The dot size and value are chosen carefully: Small dots would produce an overly sparse dot pattern. Dots that are too large would produce excessively dense dot patterns.

Figure 6.4: Dot Density Map

6.4.3 Overlays

Overlay is a spatial operation in which two or more maps or layers are superimposed for the purpose of showing the relationships between features that occupy the same geographic space. Figure 6.5 illustrates an overlay of PM_{10} and CVD deaths for the year 2010. Visually, the highest numbers of CVD deaths are concentrated in the middle of the city.

Figure 6.5: Overlay Map

6.4.4 Queries

In order to answer questions such as 'What areas have PM_{10} higher than the standards and high number of CVD deaths?', the query can be designed in ENVHIS using SQL expressions. The results of these queries are then displayed both on the map and the table. Building a query expression is a way to select features as an expression can include multiple attributes, operators and calculations. The queries can be saved as separate layers. Figures 6.6 and 6.7 provide results of a query both in a table and on the map.

Figure 6.6: Tabulated Queries

Figure 6.7: Query on Map and Table

6.4.5 Reports

A report in GIS allows to organise and display the tabular data associated with geographic features. This can be generated and distributed along with the map. Using the report wizard in ArcMap, the fields from the layer necessary to be presented as a report are chosen. All the fields to display can be chosen or the selected fields or even a subset of data based on a query may be chosen for reporting. The properties of the report may be chosen by the user too, such as style of the report, page size, font or colour.

6.4.6 Heatmaps

Heat mapping, from a geographic perspective, is a method of showing the geographic clustering of a phenomenon. Also known as hotspot mapping, heat maps show locations of higher densities of geographic entities. The 'heat' in the term refers to the concentration of the geographic entity within any given spot, and is not to be confused with heat mapping that refers to the mapping of actual temperatures on the earth's surface. Heat mapping is a way of geographically visualising locations so that patterns of higher than average occurrence of things such as crime activity, traffic accidents, or store locations can emerge.

6.4.6.1 CVD + PM_{10} hotspots

Due to the data limitations as mentioned earlier, the hotspots were discerned at the zonal level. The zones West and East were found to be hotspots with the highest CVD deaths and the highest PM_{10} deaths. However, the system would be more effective if the ward hotspots are identified so as to target interventions at those levels. To demonstrate this, a prototype system simulation has been carried out in the ENVHIS.

6.5 System Prototype

Due to the limitations in the data as discussed, the full potential of the system has not reached. Thus, this section demonstrates the possibilities of the system by improving the data and including the variables as discussed. The detailed processes and analyses are illustrated and the system functionality is also described.

i. Users of the system

It is not only the planning objectives of the system that are taken into consideration but also the major actors in the implementation arena. The user group of this system is described as the following stakeholders:

- BBMP
- KSPCB
- BCP
- Transport Ministry
- Health Ministry

Cardiologists, NGOs, researchers and the public are also described as beneficiaries of the system.

The main objective of this prototype development is to enable users to understand the significance of data improvement and their effects in a system that will provide an effective analysis that will guide the decision-making process. The key objectives of the system are not only to empower the stakeholders with knowledge and tools which assist in decisions and evaluate alternatives, but also to provide an opportunity to help them envision the system and subsequently provide feedback for any improvements to be incurred.

6.5.1 Datasets

i. Population

The population census as described is conducted every ten years and hence any analysis for the years in between has to assume the census of 2001 or 2011. To overcome this, a projected population count for every year between 2001 and 2011 was carried out and estimated using:

ESTGROWTH = (POP2011 – POP2001)/10

The estimated population for every year was determined by adding the population from the previous year with the estimated growth and so on.

For example: POP2002 = POP2001+ESTGROWTH.

The estimation of male population and female population was carried out in the same manner. Table 6.8 provides the population estimation for the years between 2001 and 2013.

Table 6.8: Projected population for years 2001-2013 in Bangalore city

YEAR	TOT_POP	M_POP	F_POP
2001	5,840,155	3,059,580	2,780,575
2002	6,098,737	3,193,752	2,904,985
2003	6,357,319	3,327,924	3,029,395
2004	6,615,901	3,462,096	3,153,805
2005	6,874,483	3,596,268	3,278,215
2006	7,133,065	3,730,440	3,402,625
2007	7,391,647	3,864,612	3,527,035
2008	7,650,229	3,998,784	3,651,445
2009	7,908,811	4,132,956	3,775,855
2010	8,167,393	4,267,128	3,900,265
2011	8,425,975	4,401,300	4,024,675
2012	8,684,557	4,535,472	4,149,085
2013	8,943,139	4,669,644	4,273,495

This method was employed to determine the population estimates for every ward in the city and the table was entered into the ENVHIS as population estimates. The choropleth maps were then obtained for the years of analysis as required.

ii. Pollution Data

The pollution data using spatial interpolation techniques from the 6 stations as mentioned in the previous section were obtained for the years of analysis and for all the wards. The values for the pollutants SO_2, NO_x and PM_{10} for the years 2006 – 2013 were obtained. This was then entered into the ENVHIS (Figure 6.8).

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Figure 6.8: Interpolated pollution values for every ward

iii. CVD Data

As explained in Chapter 2 (Section 2.4.2), the DES collects the mortality data obtained from BBMP and collates it according to the cause of death, year of death, gender and age. The spatial locations of the patients, however, are not recorded. Using the rates of deaths from this available data, the estimated CVD deaths for every ward in the city were calculated as Total Deaths, Male Deaths and Female Deaths. This data was then entered into the ENVHIS (Figure 6.9).

Figure 6.9: Estimated CVD Deaths for every ward for the years 2006-2011

6.5.2 Visualisation

Visualisation is the underpinning principle of the ENVHIS, which assists in analysis and comprehension. Visualisation functions in GIS are defined as the functions that assist users to form a mental concept or vision of information through transformation of raw simulation data.

6.5.3 Usability

The ease of interaction between user and the tool is crucial in determining the success or failure of an interactive visualisation environment (Davies and Medyckyj-Scott 1994). It is therefore important that the user interface is clear and the functions are ready to use.

6.5.4 Functions to Aid Analysis

i. Queries

As explained in the previous section, queries can be carried out on the data as per the user requirements. Queries can be classified as attribute queries or spatial queries. These queries that are used to answer specific questions for the user can be saved on the map as separate layers.

ii. Cluster Analysis

Cluster analysis is an exploratory data analysis tool that aims at sorting different objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. Cluster analysis is used to discover structures in data without providing an explanation as to why they exist. In epidemiological research, clusters of diseases can lead to very useful taxonomies (StatSoft 2014).

iii. Hotspot Analysis

Density can tell where the clusters in data exist but not if the clusters are statistically significant. Hotspot analysis in the GIS system uses vectors to identify the locations of statistically significant hotspots and cold spots in data (Figure 6.10). Points are therefore aggregated to polygons for this analysis.

Figure 6.10: CVD Hotspots in Bangalore

Hotspot analysis produces z-scores and p-values (Figure 6.11). A high z-score and a small p-value for a feature indicate a significant hotspot. A low negative z-score and small p-value indicate a significant cold spot. The higher or lower the z-score, the more intense the clustering. A z-score near zero means no clustering. On the map in Figure 6.11, the hotspots are illustrated and the names of the wards are then identified on the ENVHIS system; this will enable the stakeholders and policy makers to target the areas for interventions.

Figure 6.11: Hotspot Analysis

6.6 Summary

The aspatial and spatial analysis has demonstrated the extent of CVD in Bangalore. The calculation for the mortality rate for CVD deaths demonstrated that there are 195 deaths per 100,000 population. The YPLL has indicated that 2.1 million years have been lost due to CVD over the years 2010-2013. These are important indicators to consider as they would have a considerable impact on the economy of Bangalore. These measurements will assist the stakeholders on how best to divide up resources for CVD health improvement and preventing premature death.

The results of the inferential statistics have demonstrated that there is a statistical association between CVD and air pollution in Bangalore, especially PM10, which is a grave concern for the city. When considering gender, there was no indication to point that CVD affected either males or females more. Hence policies must be targeted for the CVD health of both genders. Zone Mahadevapura consistently showed a positive association with CVD for all four years and Zone East for two years of the analysis.

The spatial statistics visually presented the spread of CVD across the city, queries were carried out and the statistics revealed Zones West and East as hotspots. These hotspots are for non-institutional deaths, so the city would benefit from policies targeted at home deaths. Awareness campaigns on signs of CVD, knowledge of treatment options, nearest healthcare centres that deal with response to CVD would enable tackling and reduction of fatalities from the disease.

A prototype system also demonstrated the functionalities of the ENVHIS, with simulated data; in order to demonstrate the working of the system should the data quality be improved. This analysis can be repeated when the morbidity data and mortality data for institutional deaths with addresses in Bangalore becomes available. It will then provide a more accurate representation of the full extent of the disease and the hotspots.

Chapter 7: Model and Validation

7.1 Overview

The problem statement of this research, findings and the identification of the limitations such as scarcity of research output, data collection and data quality guided the development of an empirical model that would assist Bangalore in the analysis of the effects of air pollution on CVD.

This chapter aims to define the purpose of the model for this study and discusses the feedback and views received from the stakeholders. The chapter begins with an introduction to the current gaps that guided the model process; the next section presents the model and describes the components of the model. A questionnaire developed to obtain feedback from the stakeholders and the feedback received from them is discussed. Based on the responses received, the discussion in the final section provides a summary of the stakeholders' views and recommendations.

7.2 Knowledge Gaps

There is a noticeable absence of studies that highlight the harmful effects of air pollution and CVD in Bangalore. Further there is a lack of knowledge and insufficient understanding of CVD risk factors and these gaps are some of the factors contributing to the prevalence and rise of CVDs in the city/country. Based on the knowledge gaps identified in this research, a novel model is proposed to tackle the growing concern of air pollution and CVD in developing countries. The model captures the key steps to collaboratively plan the reduction of risk factors in areas and population groups of dire need. The use of Information Systems such as GIS will play a vital role in formulating policies that are targeted at population groups with an aim to prevent cardiovascular disease.

7.3 Background

7.3.1 State of Air Pollution Governance in Bangalore

This research highlighted that pollution especially pollutants such as $PM_{10,}$ is of growing concern in the city. Following investigation into the levels of the pollutants in Bangalore, a brief insight is sought into the legislation and governance of air pollution and control measures taken by the government.

The Central Pollution Control Board of India which is responsible for the air quality monitoring in the country has set up a National Air Monitoring Programme (NAMP) to provide air quality data from cities with high air pollution levels. Bangalore has been identified as one of 6 cities under the NAMP programme with high levels of pollution, and CPCB carries out source apportionment studies to identify sources contributing to those high levels. This will guide the planning of strategies and development of action plans for control and abatement of air pollution (CPCB 2009). To regulate pollution in the city of Bangalore, several initiatives have been taken by the KSPCB (TERI 2010):

1. By-passing of trucks around Bangalore
2. Installation of Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filter (DPF) devices in all pre-2010 diesel vehicles
3. Installation of DOC and DPF devices in DG sets
4. No power cuts leading to zero usage of Diesel Generator (DG) sets
5. Ban on 10-year old commercial vehicles in 2012 and 2017
6. Ban on any new industries within the city limits and fuel shift towards cleaner fuel such as Compressed Natural Gas (CNG) in existing industries
7. Wall to wall paving for reduction of road dust
8. Better construction practices
9. Conversion of public transport (commercial 3 & 4 wheelers) to CNG
10. Improvement in inspection and maintenance for vehicles
11. Inspection and maintenance for DG sets
12. Enhancement of public transport system based on CNG

The board is also working towards incorporating environmental education in the school curriculum. However, Honaganahalli and Raju (2004) states that no effort has been made to educate the general public on air pollution and its relationship with health, economy, etc. There exists a noticeable gap in the development of realistic policies and an effective legislation in the control and abatement of pollution.

7.3.2 Status of CVD Mortality

The burden of CVD to individuals, populations, society and economy has been highlighted in this research. This section will briefly provide an assessment of current CVD preventive programmes.

In Bangalore (as with the rest of the country), out-of-pocket (OOP) health expenditure contributes to 72% of total health expenditure, while the governmental expenditure (central, state and local) accounts for only 27%. This high level of OOP expenditure by individual households in India is one of the highest among low- and middle-income countries (Seshadri *et al.* 2013).

The treatment costs for NCD are almost twice as those for other illnesses. As OOP is common, this may lead to health-poverty resulting from NCD illnesses. It may also be a deterrent for regular health checks that would enable early screening of health risk factors such as diabetes, hypertension, cholesterol etc. Hence, this has to be urgently addressed by the government; this can be achieved by financing population-based interventions and offer free health screenings to detect risk factors early in order to avoid the onset or exacerbation of CVD.

The government of India has launched vertical programmes such as National Cancer Control Programmes, National Tobacco Control Programme, National Programme for Prevention and Control of Cancer, Diabetes, CVD and Stroke (NPCDCS). However, Sharma (2013) states that currently implemented programmes that address NCDs have not been able to reduce the burden due to their limited scale of deployment. In addition, resources, including medical staff who provide support, are very low in India. According to the WHO, the density of the medical workforce amounts to 6 physicians per 10,000 population, compared to an average of

14/10,000 globally. Nurses and midwives are 13 per 10,000 population, compared to 30/10,000 globally, and only 0.5 community health workers/10,000 population, compared to 4/10,000 globally.

These barriers coupled with a lack of availability of robust surveillance and research data on CVDs represent an important hindrance to the effective planning and implementation of CVD prevention and control programmes.

7.3.3 Association of Air Pollution and CVD

The scarcity of research output from Asia and India has been highlighted earlier in this research. Furthermore, a comprehensive search for research on air pollution + CVD in Bangalore returned no results. Intervention programmes and management by the government, as well as monitoring systems and public awareness programmes are required for the successful control and prevention of air pollution induced CVD.

7.3.4 State of GIS in Bangalore

Bangalore and India have a good infrastructure for GIS with a variety of potential spatial and spectral datasets. The first Indian geoportal was set up for Karnataka in Bangalore. The geoportal has been used in applications such as watershed development, minor irrigation projects, department of education, locating wasteland, etc. (Karnatakageoportal 2012). The potential of GIS, however, has not yet been fully exploited for decision support in the area of the effects of poor air quality and CVD.

Given the above arguments, a regulatory model framework will assist in the analysis of the potential association between air pollution and CVD. The model will also contribute towards strengthening the preventive attempts by the various governmental departments in their endeavours towards the improvement of the quality of air, reduction in CVD mortality and morbidity, reduction in the risks that contribute to the disease that will lead to an improvement in the health of the population, improve its quality of life and result in a positive impact on the economy.

7.4 Introduction to the Model

This research provides a new model to support the analysis of air pollution and CVD in developing countries. It has been developed to address the challenges faced by developing countries in engaging in activities involving the study of the harmful effects of air pollution. The model considers the important factors that affect the implementation of such studies. The importance and objectivity of data collection and data quality is highlighted.

7.4.1 The 5-I Model

Based mainly on the findings of this research, a 5-I model is designed and developed (Figure 7.1) that would facilitate the effectiveness of a spatial temporal methodology using GIS to better understand the effects of AP on CVD in developing countries. The model is named 5-**I** as it represents the five important components that is a synthesis of many important elements that coherently work together to produce positive health outcomes. The use of innovative technology such as GIS will result in an efficient and timely detection of disease effects and enable to act on the findings. Partnerships between stakeholders will allow focusing and working with an integrated approach to address and achieve the same goals. An integrated system will support a systematic approach and will provide a basis for an effective prevention plan that is based on timely and best evidence. The findings will also lead to prevention and intervention planning that is clearer and logical.

The model consists of five modules described as:

- IDENTIFY
- IMPROVE
- INTEGRATE
- INTERVENE
- IMPACT

The model highlights the first stage as identification of the nature of the research problem, the investigation process that might be adopted and the area to narrow down and focus on. It is vital at this stage to also identify the datasets required for the research and the stakeholders from whom the data is required. Data quality is vital, not only because of its importance in promoting high standards of healthcare but accurate, timely and accessible healthcare is important in the planning, development and maintenance of its services. Quality improvement and timely dissemination of quality data are essential to maintain healthcare at an optimal level.

The application of Knowledge Management (KM) techniques would enhance the current phase of CVD activities and synchronise disjointed knowledge in public health domain, so that there could be a more coordinated approach towards tackling CVD mortality rate in Bangalore. Bali *et al*. (2011) described knowledge management (KM) as an organisational knowledge with meaningful interaction of people, processes, activities and technologies that enable the sharing, creation and communication of knowledge. Knowledge is interpreted information, which will enable to apply the information in reasoning, decision-making, or performing actions. Based on these principles, this model will:

- Allow the creation of knowledge
- Enable the critical evaluation of knowledge
- Ensure the effective integration and application of knowledge

Public health has always been more evidence based than other health sciences. Jenicek (1997) states that Evidence-based public health (EBPH) might be seen as " *the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of communities and populations in the domain of health protection, disease prevention, health maintenance and improvement (health promotion)*". Based on this definition of EBPH, this model:

- Formulates a clear question for a public health problem
- Searches for evidence
- Appraises evidence
- Selects the best evidence for a public health decision
- Links evidence with public health experience, knowledge, and practice
- Recommends to implement useful evidences in policies and programmes
- Recommends good practice for evidence-based public health

7.4.1.1 IDENTIFY

This step includes the understanding of the research problem. An extensive background investigation will highlight the history of air pollution in the study area and the CVD scenario. The limitations of the study area with respect to background studies already carried out, population growth, criteria and characteristics of the population groups are also highlighted at this stage. Awareness of the populations about risk factors, self-management of health, behaviours and knowledge will be a basis for further exploration. Policies of government for interventions, programmes that are currently in progress and monitoring related issues will be discussed. It is also important to identify the datasets required and the stakeholders responsible for those datasets.

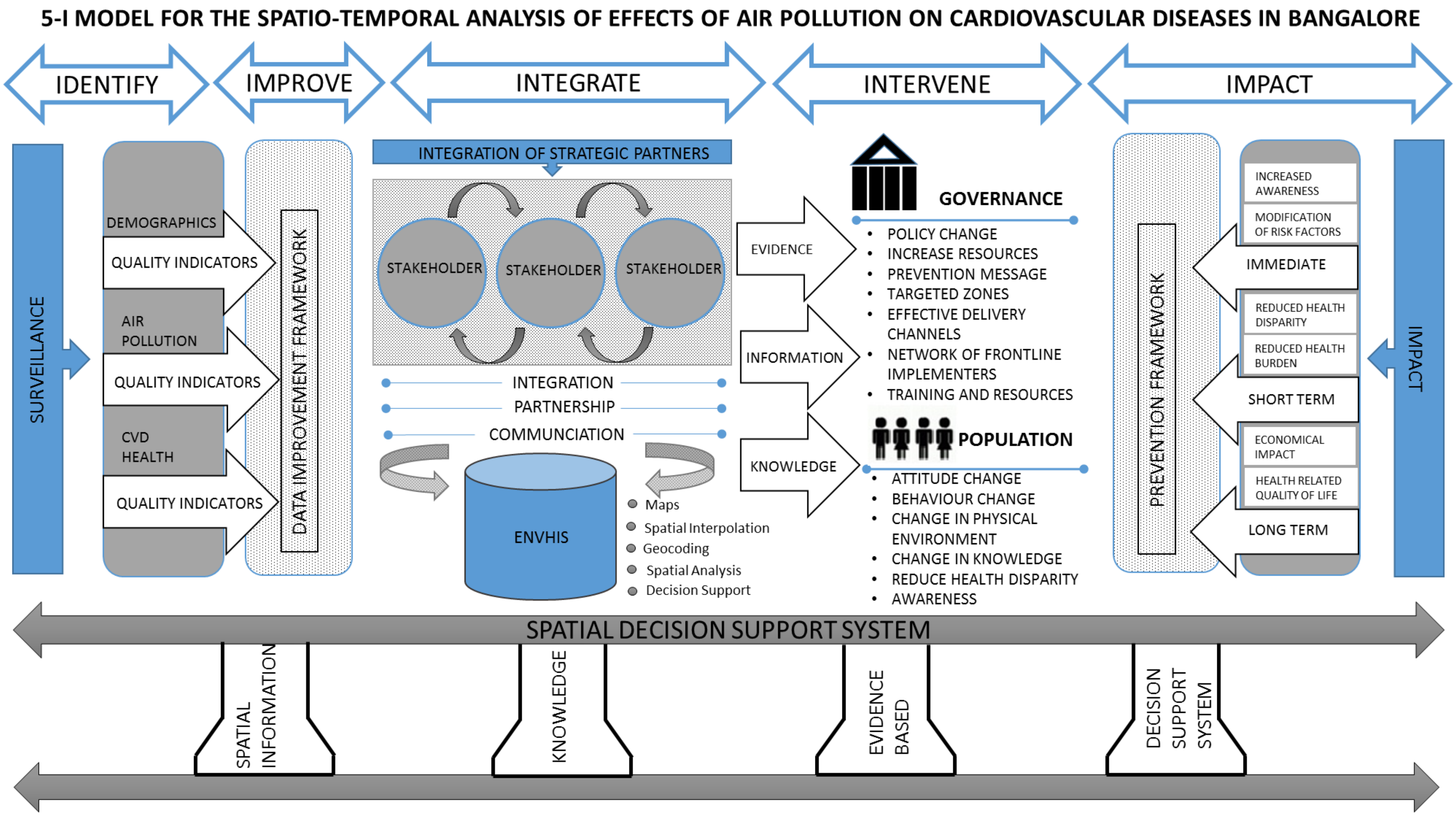

Figure 7.1: The 5-I model (See Appendix 2)

7.4.1.2 IMPROVE

The datasets required for the analysis of air pollution and CVD are to be collected, and these are demographic data, air pollution data and CVD health data. These have to be assessed against earlier defined data quality dimensions in order to determine the quality of data. The data assessment exercise includes the following steps:

1. Identify the data that need data quality assessment
2. Test for data quality parameters that include amount of data, timeliness, objectivity, relevance, completeness, accuracy and access security
3. For each of the parameters defined, assess the values or ranges
4. Review the results of the data quality assessment exercise to determine the acceptable data
5. Apply the components of the data quality improvement framework to take corrective actions in the event of data shortcomings
6. Apply the best practice of improved data handling process to prevent future recurrences and considerably improve data quality
7. Data quality assessment to be periodically repeated to monitor the application of best practice

7.4.1.3 INTEGRATE

The next step in the model is focussed on integration which can be described as:

- Data Integration
- Stakeholder Integration

i. Data Integration

Data integration involves combining data residing in different sources and providing users with a unified view of this data. Using the GIS system, data is combined and analysis performed to demonstrate the effects of air pollution on CVD in the study area. Hotspots of air pollution are determined, and relationships and patterns between environmental pollutant hazards and CVD are explored using the GIS. The spatiotemporal analysis provides an insight into how pollutants impact CVDs, and lead to the identification of areas and population groups that are most affected.

ii. Stakeholder Integration

Stakeholder integration enables the stakeholders to work collaboratively in order to facilitate change. Evidence-based strategies should be deployed to foster cooperation. An integrated approach to commissioning high quality services for the prevention of air pollution induced CVD may result in an overall total population health improvement.

7.4.1.4 INTERVENE

Based on the information and evidence from the results of the system, interventions to prevent CVD will be developed. To be effective, interventions are grouped into two groups: Governance- and population-based. A concentrated effort to integrate both interventions will result in significant improvements in air pollution and resulting CVD health.

i. Governance- based Interventions

It is any government's priority to provide public health programmes to face the challenges of environmental-related health issues. The WHO (2011b) states that over 50% of the CVDs can be prevented with early interventions. Quality treatment, early diagnosis, good quality medical and nursing care, specialist services - such as surgery and rehabilitation for those with CVD or who are at risk - will facilitate patient recovery and/or wellbeing. The government as a major priority must focus on prevention, diagnosis and treatment.

Evidence has indicated that with timely effective treatment and adequate intervention and prevention measures, the suffering due to CVD can be reduced and prevented. CVD policies are to be based on the best available evidence-based approaches that result from well-conducted, systematic reviews of the relevant evidence. Policies must evolve to incorporate the conclusions of important new research as it becomes available.

Preventive approaches require a combined effort. Pais (2006) states that risk factors tend to cluster together and it is important to identify risk factors for CVD. Co-existing risk factors multiply the risk of disease, e.g., tobacco smoking resulted in an OR for Myocardial Infarction of 3.1. The OR tripled in diabetics who smoked and tripled again if people additionally suffered from hypertension. Further investigations will determine the OR (risk factors) in the case of adding pollutants to this model.

The Indian government must initiate legislative and economic policies to increase taxes on tobacco and saturated fat, subsidise fruit and vegetables and make available facilities for walking, cycling and exercise. This requires strong advocacy and political will.

The ENVHIS system assists in the identification of hotspots of air pollution which then enables the government to take actions to reduce air pollution in the zones at most risk first; this can be achieved through the:

- Development of realistic polices and regulations for air emissions from transportation sources
- Use of ultra-low sulphur fuels
- Introduction of regular and reliable public transportation systems
- Improvement of the existing mass transit system
- Robust spot-checking, inspection and mandatory testing programmes for vehicles
- Stricter control on road-side burning of waste
- Better maintenance of roads to reduce dust from paved and unpaved roads

The ENVHIS system also assists in the identification of hotspots of CVD which then enables the government to introduce interventions in the zones at most risk first, and this can be achieved through:

- Development, implementation and monitoring policies that reduce the prevalence of CVD
- Reduce inequalities in risks of developing CVD
- Offer comprehensive advice or appropriate treatment to reduce risks

- Identify populations who have not yet developed CVD but are at risk to offer appropriate advice to prevent it
- Increased awareness among public health officials, doctors, health workers on the possible links of air pollution and CVD, and encourage to include it is a risk factor and offer advice on related health improvement
- Help raise public awareness about the health impacts of air pollution

ii. Population-based Interventions

Pandey *et al.* (2013) states that health-related poor lifestyles are widely prevalent in low- and middle-income countries such as India. Prevalence of smoking and tobacco is high, intake of dietary saturated fats; trans-fat and salt are high while fruits and vegetables intake is low. Behavioural factors such as smoking/tobacco use, physical activity, unhealthy diets lead to metabolic changes such as hypertension, raised cholesterol, raised blood glucose and obesity (WHO 2011b).

There have not been significant population-wide efforts to influence healthier lifestyles. Interventions among populations are important as better knowledge of dietary factors involved in chronic disease can lead to transformational influence on diet and other lifestyle behaviours that can have a direct impact on these diseases in the society and also be economically justifiable. For interventions to take effect it is important to make the interventions people-centric. Thus the following measure should be promoted:

- Avoid travel to highly polluted regions if possible
- Exercise or perform heavy exertion during less polluted times and areas
- Reduction in risk factors that contribute to CVD
- Reduce smoking
- Improve healthy eating and lifestyles
- The most vital of all is change in behavioural factors that contribute to CVD

7.4.1.5 IMPACT

Once the interventions have been rolled out, it is important to measure their impact at regular intervals. Without evaluation of the policies it is hard to measure what worked and what didn't.

The impact can be measured for the following main reasons to:

(i) Benefit the public
(ii) Ensure optimal use of limited resources
(iii) Maintain better standards of the healthcare provision

Health interventions are termed as a success only when they have provided a beneficial change in the health of the population. Where there is no beneficial change, the appropriateness of the intervention provided requires investigation. Hence, it is vital to monitor the outcome of health interventions in order to not only determine the change in health levels of the population but also to measure the quality and effectiveness of the healthcare provision. The impact can be measured as economical, societal or individual. The economic impact measures how the interventions and the subsequent results had an impact on the economy. Ill health adversely affects the development of human capital, which is crucial for a developing economy. The societal impact focuses on the society as a whole. Many of the risk factors that contribute to CVD are further compounded by underlying socio-economic factors as well as environment factors. The right investments will lead not only to better health, but also to longer and more productive lives. This will impact the individual, the individual's family, society and community at large.

7.5 Validation

Moody and Shanks (2003) suggest that, for effective system implementation, the perspectives of stakeholders have to be included at the validation stage. Involvement of the stakeholders in the model validation improves availability and sustainability. The validation routine has established the ability to implement the model, its reliability and acceptability to stakeholders.

A questionnaire was designed to obtain feedback from the stakeholders (Appendix 3) that addresses the key areas of the model and enables the capturing of the stakeholders' opinions on the stages of the model, the stakeholders' views on implementation of the proposed changes to data collection, proposition of integration and feasibility for implementation of the ENVHIS system and the model. A summary of the research was provided to the stakeholders' to talk them through the model; a telephonic conversation was carried out and any queries were answered.

The validation participants are five governmental departments' stakeholders who were individually consulted to comment on and evaluate the implementation of the 5-I model activities. The departments are listed below and the profile of the stakeholders is briefly described in Table 7.1:

- Transport Department (TD)
- Bruhat Bangalore Municipal Corporation (BBMP)
- Department of Health and Family Welfare (DoH)
- Karnataka State Pollution Control Board (KSPCB)
- Bangalore City Police (BCP)

These stakeholders were selected as they are the key players in implementing policies in Bangalore that pertain to environment, infrastructure, road and traffic management and health. Their major roles as applicable are described in Table 7.1.

Table 7.1: Profile of Stakeholders

STAKEHOLDER	RESPONSIBILITIES
Transport Department	Various transport-related matters and all activities relating to decision making pertaining to transport.
BCP	Bangalore City Traffic Police is a specialised unit responsible for overseeing and enforcing traffic safety compliance on city roads, as well as managing the flow of traffic.
BBMP	Bruhat Bangalore Mahanagara Palike translates to Greater Bangalore Municipal Corporation and is the administrative body responsible for the civic and infrastructural assets of Bangalore city.
Department of Health and Family Welfare	The DoH and Family Welfare unit implements various National and State Health programmes of Public Health to provide comprehensive health care services to the people of the state through various health and medical institutions.
KSPCB	The Karnataka State Pollution Control Board is responsible for the prevention and control of environmental pollution, and provides for the prevention, control and abatement of air pollution.

7.5.1 Stakeholder Feedback on the Research Model

This section briefly provides a discussion of the feedback and comments of each question in the questionnaires as received. The original responses from the stakeholders are attached in Appendix 4.

Question 1: **What is your view on the 5-I model developed for the spatiotemporal analysis of effects of air pollution on cardiovascular health?**

Discussion of the Stakeholders' Responses: With respect to the 5-I model, the majority of the stakeholders expressed positive views on the model. They state that the model is excellent, is comprehensive, effective and an excellent DSS. They deem the model to be good and accurate to address the effects of AP and CVD in a rapidly developing city such as Bangalore. They also stated that it is advantageous to both the government and the citizens who will benefit from the system. Although the stakeholder KSPCB express their concern that it may be difficult to establish an exact linkage between an increase in AP only to CVD and also that CVD may not be independently affected by AP, they state the model will be useful in the spatiotemporal analysis of environment related CVD.

Question 2 - BBMP Demographic Data

The research analysis highlighted the inclusion of variables such as age-wise breakdown of deaths to assist in estimation of the death rate; do you think this inclusion can be addressed by the BBMP? If not, why?

Discussion of the Stakeholders' Responses: The stakeholders expressed that it may be possible to include the variables that will assist in analysis of death rates according to the recommended variables.

KSPCB (Air Pollution Data)

The research analysis highlighted the need for increased fixed stations air quality monitoring for assessing long-term effects on health and the inclusion of wider $PM_{2.5}$ monitoring; do you think these criteria can be addressed by the KSPCB? If not, why?

Discussion of the Stakeholders' responses: The stakeholder expressed that due to the variability of the pollutant in the atmosphere and dependency on other factors such as temperature, velocity, wind direction, they do not believe in increasing the number of monitoring stations.

BBMP (CVD DATA)

The research analysis highlighted areas of improvement to the present collection of mortality that will aid in improved analysis of disease outcomes; do you think this data improvement framework is possible to be adopted by the BBMP? If not, why?

Discussion of the Stakeholders' responses: The stakeholders expressed that they will consider the recommendations proposed for the collection of mortality data.

Question 3: This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?

Discussion of the Stakeholders' responses: The stakeholders state that the use of GIS is not just essential but a necessity, they state that it will be an advantage that will enhance the information management and prevention. They agree that it is certainly beneficial to Bangalore. The added fact that a National GIS approach is implemented in the country sounds encouraging for this implementation.

Question 4: Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not why do you believe it would not and what would you suggest to make it a better model?

Discussion of the Stakeholders' responses: The stakeholders were asked if they think the implementation of GIS in feasible in Bangalore. The stakeholders unanimously agree that this is feasible in Bangalore, they state that Bangalore with its reputation for IT is the best location for the implementation of this model. A stakeholder commented that although Bangalore/Karnataka has made progress in using GIS, a system focussing on environment and health is important, they think that GIS could play a vital role in decision making. There is an added advantage that the city is very IT advanced and Karnataka was the first state to set a geoportal in India.

Question 5: The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?

Discussion of the Stakeholders' responses: In response to the question if GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, the stakeholders highlight that there is a growing concern of air pollution and that as a risk to CVD is quite novel and a framework would certainly be useful. The stakeholders agree that GIS can reap a demographic transition and raise awareness. But they also add that there has to be a focus on awareness of diet, lifestyle etc. that largely rests with the individual itself. Further one stakeholder suggests that other factors have to be considered too, some of the factors have been considered in the analysis in this research, but some of the factors such as exposure were outside the scope of this research.

Question 6: As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, DES and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such cooperation is achievable, if not what could be the restraining factors?

Discussion of the Stakeholders' responses: The model highlighted that a collaborative working of the stakeholders is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health. In response to this, all stakeholders agree that cooperation is achievable, it requires essential planning and coordination to work towards the same goal, one stakeholder also states that with the desired aim, results can only be achieved through collaboration, in the interest of the overall health of the general public.

Question 7: In addition to the above, do you have additional comments regarding the system/model or the research itself?

Discussion of the Stakeholders' responses: The stakeholders commented that Bangalore needs a system such as GIS that is a robust Decision Support System. The focus on air pollution and CVD that is novel is beneficial to the city. Apart from CVD, a system such as this would benefit other air pollution induced health effects such as respiratory diseases, lung diseases, asthma, etc.

7.6 Summary

This chapter discussed the feedback and comments on the model from the different stakeholders. The recommendations to and any further refinement to the model were also discussed in this section. Overall the model was deemed comprehensive by the different stakeholders; all the stages of the model were considered appropriate and useful for addressing the air pollution induced issues in CVD. The use of a GIS system was considered appropriate, useful and even essential. The parameters proposed for improving quality of data was stated to be considered for inclusion. The need for collaborative working amongst the relevant stakeholders working towards the same goal was validated. Interventions were focused on government policies and those directed at population groups who are at high risk of developing CVD and who may be vulnerable to air pollution.

Some of the inputs to add to the proposed model are also suggested. For instance there is a need to:

- Study the effects of air pollution on ailments other than CVD
- Medical studies to understand the cause-effect relationship
- Increasing the number of stations
- Assessments of lifestyle, hereditary factors, smoking etc. in addition to air pollution
- Place of abode, accessibility to healthcare services, exposure to pollution concentration and duration

In light of these comments, the following recommendations are proposed to facilitate the successful implementation:

- Plans should be made to achieve pollution exposure and CVD health relationship with the support of the KSPCB and other departments; steps can be taken to further conduct studies to determine these
- The GIS system is scalable; this implies that with the existing base maps, thematic maps, demographic data, etc., the system can be extended to include other health-related data such as respiratory diseases, asthma, lung cancer, etc., that are attributed to air pollution

- This study considered the mortality and this did not include other backgrounds of the patient; the variables such as the modifiable and non-modifiable risk factors can be monitored and included over time that can aid in future analysis
- The scope of this study was limited to the effects of air pollution on mortality; the morbidity/CVD prevalence studies maybe carried out using the same system

To summarise, overall, this model was deemed appropriate for a city like Bangalore where the air pollution and CVD are of grave concern. Incorporating the proposed criteria (outlined in the model) would enable the development of a robust system to tackle air pollution and its effects on CVD. This system can be also scalable to include other health factors in Bangalore city. With minor changes, this model could be applicable to other similar cities in India, and with further investigations and modifications could be equally tested for other developing cities around the world.

Chapter 8: Conclusions, Limitations and Further Research

8.1 Research Summary

The aim of this research was to design, develop and evaluate a model that supports the spatiotemporal analysis of the effects of air pollution on CVD in developing countries. To achieve this aim, a case study was chosen in a fast-paced developing economy to explore the magnitude of the levels of air pollution, its sources and the AQM policies. It also explored CVD in the chosen case study area, the risk factors as applicable to the area and policies of the city on cardiovascular health. The background of the GIS infrastructure was also investigated to provide an insight into the way recent technological advances can be adapted to the research objectives. Drawing on the results from the analysis and with the knowledge and the background of the research study area, the 5-I model based on GIS was designed that would assist in the assessment of the effects of air pollution on CVD in rapidly developing cities.

8.2 Originality of the Research

Any PhD research has to demonstrate originality and make a significant contribution to knowledge in the research domain (Baskaran 2008, Dwivedi 2004) and this research has met these criteria requirements, a summary of which is provided in Table 8.1.

Table 8.1: Summary of Research Originality

Criteria for Research Originality	**Evidence in Thesis**
Evidence of major investigation	• Assessment of air pollution as a risk factor to CVD in Bangalore city
Data sources	• Demographic data • CVD Mortality data • AQ Data
Data use	• Analysis using both spatial and non-spatial techniques
Carrying out empirical work that hasn't been done before (Originality in outcomes)	• Data quality assessment • CVD Mortality trends • Association of AP and CVD in Bangalore • Spatial Interpolation of AP • Mapping using GIS and determining hotspots • Design of the prototype system • Model to aid in assessment of air pollution and CVD for developing countries
Ability to make critical use of published work and source material	• Use of relevant and recent references from all the various areas of the research • Demonstration through Literature Review
Setting down a major piece of new information	• Data Improvement Framework • Development of an application on a GIS platform to enable analysis of AP and CVD • Model to assist assessment of effects of AP on CVD
Potentially publishable	• 4 IEEE Conference publications • 2 Journal Publications • 2 Journal Papers (work in progress)
Being cross-disciplinary	• True cross-disciplinary work of Computing, Environment, Health and Geography
Adding knowledge in a way not done before	• This thesis has designed, developed and evaluated a novel model to enhance the activities of air pollution and CVD in developing cities. • This original research will influence the development of future works

8.3 Objectives Accomplished

The introductory chapter provided the objectives of the research. Based on these objectives, the accomplishments of this research are provided and summarised in Table 8.2. The summary of key contributions is covered in detail in Section 8.4.

Table 8.2: Accomplished Objectives and Corresponding Outcomes

Objectives	Thesis map	Outcomes
Explore the CVD and Air Pollution background in a case study of Bangalore, identify specific barriers and investigate the data collection processes to assess any limitations	Chapter 2 Chapter 3	• Explored current approaches • Identified specific barriers to these studies in developing countries • Limitations identified • Monitoring related issues • Data collection process • Data set characteristics • Limitations of obtained data
Develop an application to be used on a GIS based platform that supports spatiotemporal analysis of the effects of air pollution on CVD in Bangalore;	Chapter 4	• Main system components • Data Requirements • Data types • Data Modelling
Develop a Data quality framework that recommends procedures to improve data quality in Bangalore	Chapter 5	• Data Quality Parameters • Data Quality Improvement Framework
Demonstrate the analysis of CV mortality and concentrations of PM_{10}, SO_2 and NO_x to determine hotspots in Bangalore	Chapter 6	• Descriptive Statistics • Inferential Statistics • Association of AP and CVD in Bangalore while controlling for other factors • Choropleth Maps • Spatial Interpolation • Spatial Analysis
Use the research carried out in Bangalore, develop and evaluate a generalisable empirical model that could, using existing topographic, environmental, demographic and health records, strengthen decision-making in healthcare management in developing regions with incomplete monitoring and with data quality issues	Chapter 7	• Design and development of 5-I model • Validation of model by stakeholders

8.4 Summary of Key Contributions

The primary contribution resulting from this research deals with the main research question: Provide a new approach/model to better understand the effects of air pollution on CVD in developing countries. The model developed to achieve this has advantages in the context of a developing country. The significant contributions that emerge from this study are reviewed in some detail in this section.

8.4.1 Contribution to Body of Knowledge

As highlighted in Chapter 1, research relating to the effects of air pollution on CVD in developing countries is not common, with only 10% of referenced studies emerging from Asia. Furthermore, there is an obvious scarcity of studies from India; Bangalore has no studies in this area. With consideration to the fact that every city/area has its own unique characteristics, studies that highlight the research problem in the context of that specific area is essential. With this background, this research makes a tangible contribution to the body of knowledge of assessment of air pollution on CVD.

8.4.2 Novel Use of Methodology

The use of GIS in healthcare is not new. GIS has been used in health interventions to map distances from point sources of pollution, in interpolating pollution, in mapping communicable diseases, etc. But the application of a GIS using the existing datasets to assess the levels of pollutants and their effects on CVD in the context of a specific developing city with its own set of characteristics is novel.

8.4.3 Mortality Data from Bangalore

There have been no studies exploring the CVD mortality data obtained from BBMP. The access to the mortality data from BBMP has not been allowed before. Also there have been no independent studies that have researched the mortality trends in Bangalore, specifically the CVD mortality trend.

8.4.4 Data Quality Limitations

The data quality issues that resulted from an initial analysis of the dataset are an important contribution of this study. Determining the limitations of the current data collection and highlighting the objectivity of the data collection process would enable not only further research, but also result in other advantages such as better health management and economic impact for the government of Bangalore. The framework that resulted from the data quality exercise will enable better monitoring of data that will aid in strengthening health development policies.

8.4.5 Air Pollution and CVD in Bangalore

In terms of exploration of air pollution as a risk factor for CVD, this research overcame the limitations of the air pollution data by using the spatial interpolation techniques of GIS which demonstrated that developing cities can benefit even with limited monitoring stations. Moreover this air pollution data, along with the CVD mortality data, was used to determine results from multivariate logistic regression analysis to identify associations between the variables and gain a better understanding of the likely risk factors. This is also an impetus to generate more intervention plans to address air pollution and CVD issues in Bangalore. The estimated number of productive years lost due to CVD, i.e., 2.1 million years, is an important factor to consider, as preventive measures taken by the Government will result in a significant economic impact on the city.

8.4.6 Development of the 5-I Model

This research makes a significant contribution by designing and developing a model that provides the stages to be adopted to conduct an analysis of the effects of air pollution on CVD and plan prevention policies according to areas at risk and populations in need. The highlighting of hotspots in major cities would enable cost-effective prevention activities to be rolled out. The knowledge and awareness of populations in the areas highlighted is also significant, as it is not only the government's responsibility to improve health, but also citizens should share responsibility by improving behaviours that contribute to risk factors.

8.5 Research Constraints and Limitations

There were certain limitations to the study:

1. This research emphasises the use of technology such as GIS. Although this may work well for Bangalore and India, one has to consider an effective implementation strategy because the expertise to use GIS may not be available in some developing countries.

2. This research provided the hotspots for air pollution and CVD. Although this is a contribution to the study, one has to be mindful that the air pollution data used is interpolated data from 6 stations and the use of data from more stations would produce more robust results.

3. This research only considered the mortality data for CVD, as collecting morbidity data posed a challenge. The health recording system is not comprehensive in Bangalore and patient records with a background of health history are not available. Hence, the prevalence of CVD and the effects of air pollution on morbidity could not be determined.

4. The analysis only considered the 'home' records of CVD mortality as the spatial location of the hospital records was not available. This resulted in assessing only half of the deaths in Bangalore.

5. Risk factors, such as background on smoking, hypertension, alcohol consumption, BMI, diabetes, cholesterol levels, occupation and lifestyle were not considered in the analysis as they are not available. Collecting data on these factors would prove beneficial for the analysis.

8.6 Future Work

Leading on from the previous section, the limitations of this study can also be the basis for the future work in this area. There are further opportunities to explore other areas of this research study.

- **Implement the 5-I model in other rapidly growing cities in India and other developing cities in the world**

  The other megacities in India have similar characteristics of Bangalore and the issues related with air pollution and CVD; data collection methods and issues are also similar. The 5-I model developed will provide a good framework for these cities to follow and assess the situation in order to implement policies that will favour the health and well-being of the populations. The 5-I model can also provide a basis for other developing cities in Asia and across the world. On assessing the background of a city, with some changes to the model as necessary, the model can be a good framework for other cities to work with.

- **Assess the effects of air pollution on other related health effects using the GIS system**

  Asthma is a burden on communities, with significant public health and financial consequences. Bangalore has a growing asthma concern. Asthma is not only related to genetic and environmental factors, but is also believed to be affected by air pollutants like PM, O_3 and SO_2. Literature on asthma studies has shown a large geographic variation at local/community level. The GIS system with existing base maps, demographic data (and asthma data) can be developed to provide robust spatiotemporal patterns and trends of the disease.

- **Assessment of pollutant levels and analysis of CVD morbidity using the same GIS system**

  Population-based/cohort studies on samples may be conducted to determine the morbidity from CVD. CVD is said to affect Indians about 10 years earlier than their Western counterparts and many health providers stated that they are increasingly seeing younger patients with CVD. The strength and success to Bangalore’s economic growth is its youth (under 40's - 50's), it is vital to assess this risk group and their exposure to air pollution. This group is also the highest mobile group due to their professions; an assessment of their behavioural factors, attitudes to CVD and exposure to pollution can be assessed and mapped using the GIS system. By protecting the people, the community and the economy can be protected.

- **Assessment of CVD mortality and morbidity and levels of pollutants in rural settings in developing countries**

  Rural settings in developing countries have other additional challenges such as poverty, lower socio-economic status, and lower access to primary and preventive healthcare. This, in addition to material deprivation, adoption of unhealthy behaviours (such as alcohol, drug and tobacco abuse) along with challenges such as education and employment, collectively contribute to CVD. Further research may be conducted in this area.

- **Screening of risk groups to air pollution exposure and risks to cardiovascular health**

  There is a hypothesis that women who are exposed to high levels of fine PM, specifically during pregnancy, and particularly during their third trimester, may face up to twice the risk of having a child with autism than mothers living in areas with low particulate matter. If associations are found in Bangalore through further investigations into this area, they will result in the development of important policies that protect vulnerable women and babies.

- **Estimate of costs of CVD to households and calculation of macro-estimates of CVD costs to Bangalore's economy**

  There have been no studies that consider the estimation of cost of CVD on households and communities. A cost-benefit analysis exercise will assist in formulating prevention programmes and policies to reduce the impacts of air pollution induced CVDs.

- **Raising the awareness of healthy lifestyle behaviours in CVD prevention through a social KM approach**

  Bangalore and India are technologically advanced. For a population of 1.2 billion, India has 7.52 million telephones, and it has the highest number of mobile subscribers in the world. The awareness of healthy lifestyle behaviours for CVD prevention and behavioural factors for reduction of environmental pollution may be made through the use of bespoke social KM tools. This is a novel methodology which uses GIS spatial analytics with Hadoop to analyse structured and unstructured big data that will provide the most relevant and updated information for decision makers.

8.7 Concluding Remarks

It is believed that this thesis has made a significant contribution to the body of knowledge, involved stakeholders and their collaboration. The study has enabled presentations in a number of conferences, plenaries and poster presentations. It has also resulted in a number of publications with a scope for further ones.

Bangalore city has been able to consider the use of the model GIS system and implement it for the benefit of the city and the well-being of its citizens. The study trusts that the concepts and analyses undertaken can provide valuable knowledge on the use of a GIS based model to assess the air pollution effects on CVD not only in Bangalore but also in other cities in India, as well as in other developing cities in the world.

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Appendix 1

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Figure 5.2: Bangalore Population – 2001

Figure 5.2: Bangalore Population – 2011

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Figure: Fixed AQMS Bangalore

Figure: Buffer for AQMS

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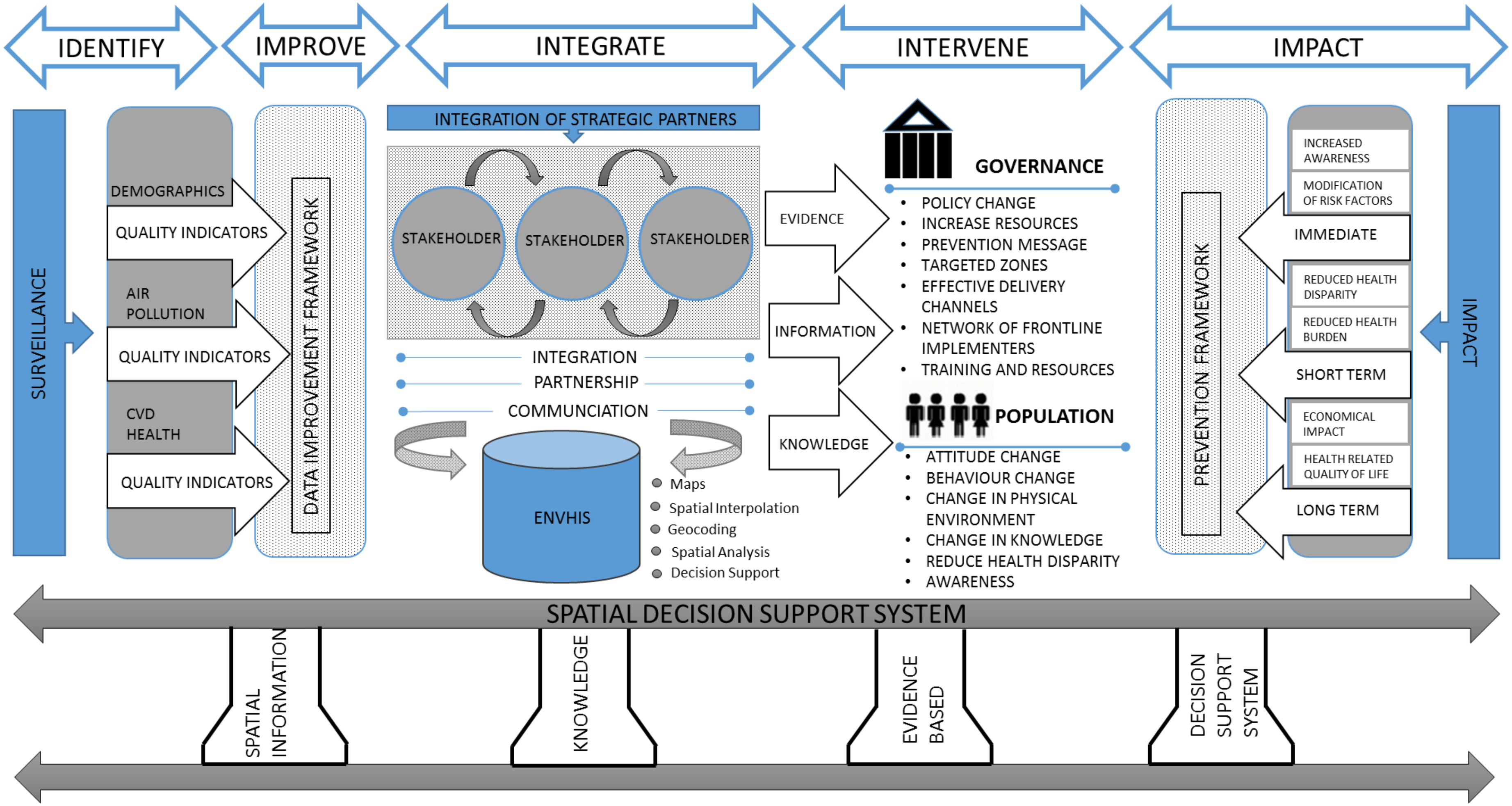
Appendix 2

5-I MODEL FOR THE SPATIO-TEMPORAL ANALYSIS OF EFFECTS OF AIR POLLUTION ON CARDIOVASCULAR DISEASES IN BANGALORE



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Appendix 3

EVALUATION AND FEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?

2a	DEMOGRAPHICS DATA: The research analysis highlighted the inclusion of variables such as age-wise breakdown of deaths to assist in estimation of the death rate; do you think this inclusion can be addressed by the BBMP? If not, why?

2b	CVD DATA: The research analysis highlighted areas of improvement to the present collection of mortality that will aid in improved analysis of disease outcomes; do you think this data improvement framework is possible to be adopted by the BBMP? If not, why?

2c	AIR POLLUTION DATA: The research analysis highlighted the need for increased fixed stations air quality monitoring for assessing long-term effects on health and the inclusion of wider PM2.5 monitoring; do you think these criteria can be addressed by the KSPCB? If not, why?

1

3	This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?

4	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?

5	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?

6	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?

7	In addition to the above, do you have additional comments regarding the system/model or the research itself?

NAME: ___________________________________

POSITION: ________________________________

DATE: ____________________________________

3

Appendix 4

RESPONSES

BBMP EVALUATIONAND FEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?
	The proposed model for the spatial-temporal analysis appears to be a very comprehensive model. What is interesting is that it provides a detailed and accurate consideration to the appropriate factors that need to be addressed.

2a	DEMOGRAPHICS DATA:The research analysis highlighted the inclusion of variables such as age-wise breakdown of deaths to assist in estimation of the death rate; do you think this inclusion can be addressed by the BBMP? If not, why?
	The age-wise breakdown is already being collected in the forms (hardcopy) manually, the IT database does not however include the variables, and this can be undertaken with very little change. However it would require more time, extra support and training to staff in data input and data management which will be considered in our next review.

2b	CVD DATA:The research analysis highlighted areas of improvement to the present collection of mortality that will aid in improved analysis of disease outcomes; do you think this data improvement framework is possible to be adopted by the BBMP? If not, why?
	We have a very good existing system and practice for the collection of mortality data. We will certainly try and address the raised criteria in the research on the variables and processes as mentioned in our next review.

3	This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?
	Yes, it will definitely assist in addressing the issue. The use of GIS systems is more widespread now and a National GIS approach is thrusting the use of GIS applications in planning and development activities. This model of GIS for air pollution and cardiovascular health can play an important role in the prevention activities going forward.

1

4	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?
	Karnataka state was a pioneer in India to set up the first geoportal in India. This model that you have designed is feasible to fit in the geoportal with the aim as a Health geoportal and shall be considered going forward.

5	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?
	The introduction of air pollution as a risk factor for cardiovascular disease is quite novel in Bangalore. There certainly is a growing concern for the level of pollution in the city, a framework as the one you have developed will be very useful in the prevention activities.

6	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?
	Yes, cooperation and collaborative working is achievable. This will require a lot of planning and mutual agreements between the various ministries and departments, there has to be a board with members formed from each department who will work towards the common objective and common goal.

7	In addition to the above, do you have additional comments regarding the system/model or the research itself?
	The 5-I model appears comprehensive and highlights all the important stages that will assist in formulating prevention policies. But apart from CVD,air pollution also affects other major diseases such as respiratory diseases, lung disease, asthma etc. the model could provide to analyse these effects as well and include it in the prevention and monitoring framework.

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2

BCPEVALUATIONAND FEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?
	My view of this 5-I model is that it is an excellent decision-support system that will be advantageous to the various departments of the state of Karnataka and its citizens who will benefit from this system.

2	This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?
	The GIS is not justessential but is now an urgent necessity—so as to empower itscitizens and bring an inclusive economic growth and prosperity to its people.

3	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?
	Yes, the GIS based model is feasible in Bangalore.Various Information Technology tools are already being implemented for providing various citizen services and government programme outreach in the city and state. There is a scope for thrusting the use of GIS applications into governance, planning and development activities. While Karnataka has made progress in usingGIS, a system such as this focusing on environment and health is very important and timely for the state to adopt.

4	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?
	A system such as GIS can reap a demographic transition by preventing cardiovascular diseases, expedite development and eventually reduce disparity bringing more equity among the citizens.

5	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?
	Collaboration has to be planned so as to ensure that there is seamlessinteroperability and cooperation between the stakeholders who work towards the same vision of managing environmental pollution to reduce health risk such as heart disease and other diseases.

6	In addition to the above, do you have additional comments regarding the system/model or the research itself?
	This appears a useful model and is of great relevance to the needs of this city, by focussing on reducing pollution and its risk to health, a system such as this will bring growth, transparency, equity and inclusiveness. It is appreciable that researchers like you are promoting research for the city of Bangalore that will benefit from studies that assess environmental pollution and risks on health.

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HEALTH MINISTRY EVALUATIONAND FEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?
	The model with the five stages described appears to be very effective. It provides a comprehensive understanding of the stages that will assist in assessing the effects of air pollution and health implications.

2	This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?
	Prevention is certainly the first step before cure. Systems are necessary in the city now that will tackle the pollution. The use of GIS systems for prevention I believe will be an advantage that will enhance the information management and prevention.

3	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?
	Yes, this GIS model is feasible in Bangalore. GIS is not only technology-centric but also is decision- centric and could play a vital role in decision making. However readily usable data must be available for application and decision making.

4	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?
	Yes, this GIS system can play a vital role in formulating prevention policies. But there has to be focus also on awareness of the risk factors among public such as the choice of diet, lifestyle, etc. that rests largely with the individual. A health information system based on this GIS can be used to provide information and raise awareness.

1

	5	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?
		Cooperation is achievable and if planned properly would work very well. A collaborative working is essential to assess the developmental needs of the population, bridge disparity and promote equity and inclusivity.

	6	In addition to the above, do you have additional comments regarding the system/model or the research itself?
		Bangalore needs robust information and decision support systems to aid in decision making processes for planning and implementation of various departmental programmes. GIS will be a pillar around which such information and support systems can be built. Your research model has exactly provided that strategy to support in healthcare that will have a tremendous impact.

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TRANSPORT MINISTRY EVALUATIONAND FEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?
	My view of this 5-I model is that it is excellent and covers all the important and relevant stakeholders, overall a very good model to identify and address the effects of air pollution on cardiovascular diseases in a rapidly developing city like Bangalore.

2	This research model focuses on implementing a Geographical Information System (GIS), do you believe this will assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?
	The potential of GIS has not yet been fully exploited in areas such as health and environment. This initiative will certainly be beneficial to Bangalore and its citizens.

3	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?
	The implementation of the proposed GIS based system is feasible in Bangalore. The city is very advanced with the use of IT technology and has over the last two decades successfully borne the invasion of information technologies and kept up with it. Bangalore probably is the best location for the implementation of this model being the Silicon Valley of India.

4	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?
	GIS can definitely play an important role in formulating policies. It can probably be used to monitor the roll-out of these programmes, help in raising awareness and monitor the progress of interventions.

5	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?
	Collaboration is achievable, all activities have to be clearly planned and coordinated among the many stakeholders. Programs have to be made so that the stakeholders can meet regularly through workshops for this purpose.

6	In addition to the above, do you have additional comments regarding the system/model or the research itself?
	The scope of this model clearly lies within the remit of the GIS activities. The added advantage being that the use of GIS particularly in air pollution and cardiovascular disease is novel for developing countries and it is interesting that the model has been tested as a prototype for Bangalore to ascertain its reliability with all the possible modifications specified.

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KSPCB EVALUATIONANDFEEDBACK

1	What is your view on the 5-I model developed for the Spatial-temporal analysis of effects of air pollution on cardiovascular health?
	It is difficult to establish exact linkage between increases in air pollution only to CVD Air pollution may aggravate the prevailing problem in the patient, but may not cause CVD independently. As we all know that ambient air quality data is used for the study (concentration of pollutants in the ambient air) which consists of different pollutants emanated from variety of sources. We may find it difficult to attribute the air pollution only to CVD. However with some control factors, I feel the proposed model can be used to make spatial-temporal analysis of air pollution impact. But one should be careful to choose the control parameters. It may also become necessary to have medical examination of the affected people to justify the cause-effect relationship.

2	AIR POLLUTION DATA: The research analysis highlighted the need for increased fixed stations air quality monitoring for assessing long-term effects on health and the inclusion of wider PM2.5 monitoring; do you think these criteria can be addressed by the KSPCB? If not, why?
	As we all know that the meteorology varies with time (even for short duration if the velocity in the atmosphere is more due to unforeseen reason) a space. It may not be feasible to have an accurate data of the pollutants at the given location and at any given point of the time. We can make necessary assumptions to extrapolate the air quality data collected from specific monitoring station. Further we also know that the transportation and concentration of pollutants at any given location dependents on temperature, point source, wind velocity, atmospheric stability, wind direction etc. Hence increasing the number of air quality monitoring stations will not serve the purpose and will not help in assessing long term affect on health.

3	This research model focuses on implementing a Geographical Information System (GIS), do you believe this well assist in air pollution and cardiovascular disease prevention activities? If not, what do you think are the barriers?
	The idea of the using GIS is good, but will it help to superimpose the temporal-spatial air pollutant concentration to CVD needs to be checked. As far as health data from the hospitals on aliment of CVD is concerned, we don't have registration of patients in the ICD (International Code of Disease) format and we may not get the exclusive segregated data on CVD. Sometimes it also happens that the patient will be admitted to some problem and get registered for the department, but after detailed examination it will be diagnosed as CVD and will be treated. But in the original registration he will be registered always in the first diagnosis. He may not be truly reflected in the CVD. So it may be difficult to get the required qualitative & quantitative data which can be used in this GIS software and also in SPSS analysis.

1

4	Do you think the implementation of the proposed GIS based model will be feasible in Bangalore? If not, why do you believe it would not and what would you suggest to make it a better model?
	Yes, provided certain controlling parameters and assumptions are made while attributing CVD with increase in air pollution.

5	The GIS based system can play a vital role in formulating policies targeted at population groups for preventing cardiovascular diseases, do you agree with this, if not why?
	GIS based application can only be used to interpret the existing database and can be considered as guiding factor for evolving efficient policy to curb impact of increase in air pollution to CVD. However one should be careful while interpreting the data as there are many factors like food habits, resistance to particular disease, smoking habit, life style, etc will play main role among the people. Further all the people suffering from CVD cannot be considered only due to air pollution as we have to consider other socio-economic factors like age, sex, place of stay, profession, accessibility to health care, affordability, time of exposure to air pollution, concentration & duration of exposure etc.

6	As highlighted in the model, a collaborative working of the stakeholders (BBMP, KSPCB, BCP, Transport Ministry and Health Ministry) is essential for a successful implementation of preventive policies for tackling air pollution and effects on cardiovascular health, do you believe such co-operation is achievable, if not what could be the restraining factors?
	Yes, it can be achievable in the interest of the overall health of general public. It is also necessary as any one stake holder cannot achieve the desired goal or effectively implement the proposed policy.

7	In addition to the above, do you have additional comments regarding the system/model or the research itself?
	It is also necessary to segregate the pollutants and study which pollutant is more significant for aggravation of CVD and also to have cumulative effect of different pollutants present in the ambient air. Integration of health data with other factors apart from increase in air pollution is also necessary to develop dose- response relationship. It is also necessary to determine the relationship between the changes in exposure to environmental pollution and to use this relationship to predict the changes in the CVD pattern associated with specific changes in the environmental pollution and exposure to pollution, If required epidemiological studies can be carried out on the specific environmental problem to arrive at the cause-effect relationship.

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Appendix 5

Certificate of Ethical Approval

Applicant:

Anitha Chinnaswamy

Project Title:

A Methodology and Toolkit for the spatiotemporal analysis of air pollution and cardiovascular disease in Bangalore, India

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

20 April 2015

Project Reference Number:

P32874

Medium to High Risk Research Ethics Approval

Project Title

A Methodology and Toolkit for the spatiotemporal analysis of air pollution and cardiovascular disease in Bangalore, India

Record of Approval

Principal Investigator

I request an ethics peer review and confirm that I have answered all relevant questions in this checklist honestly.	X
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	X

Name: Anitha Chinnaswamy..

Date: 27/03/2015..

Student's Supervisor (if applicable)

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Name: Chrisina Jayne ....

Date: 17/04/2015..

Reviewer (if applicable)

Date of approval by anonymous reviewer: 20/04/2015